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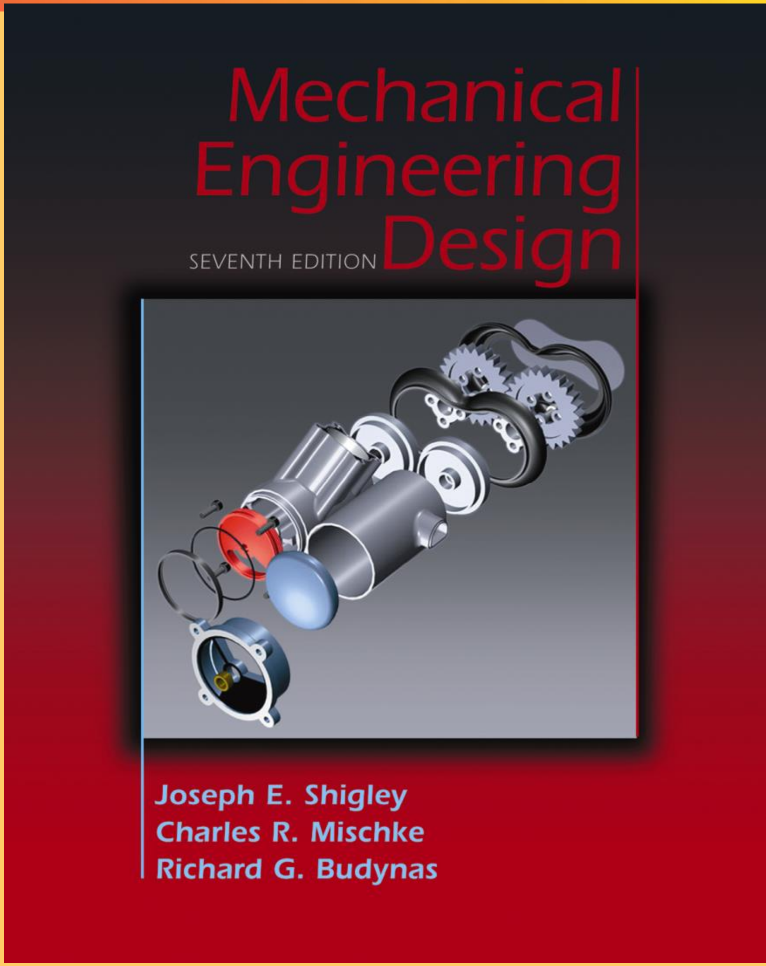
Chapter 13

Gears - General

Mechanical Engineering Design

Seventh Edition

Shigley • Mischke • Budynas



Types of Gears

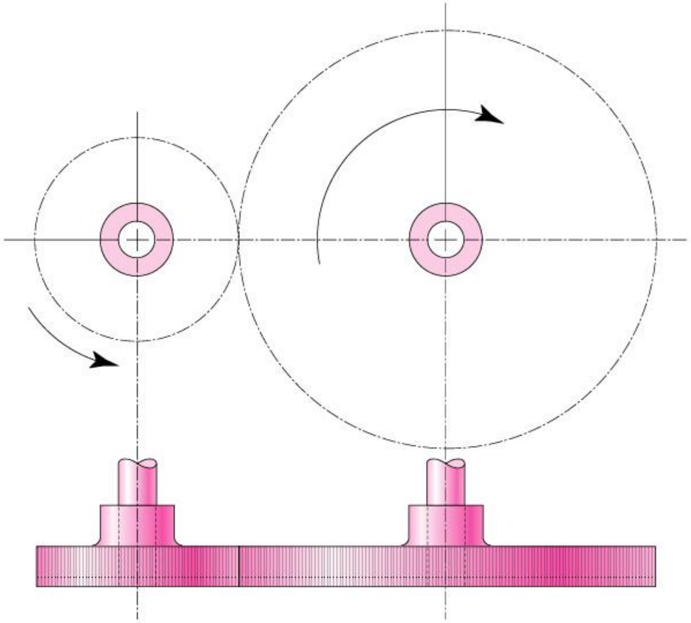


Fig. 13.1 Spur gears have teeths parallel to the axis of rotation. They are used to transmit motion from one shaft to another, parallel, shaft.

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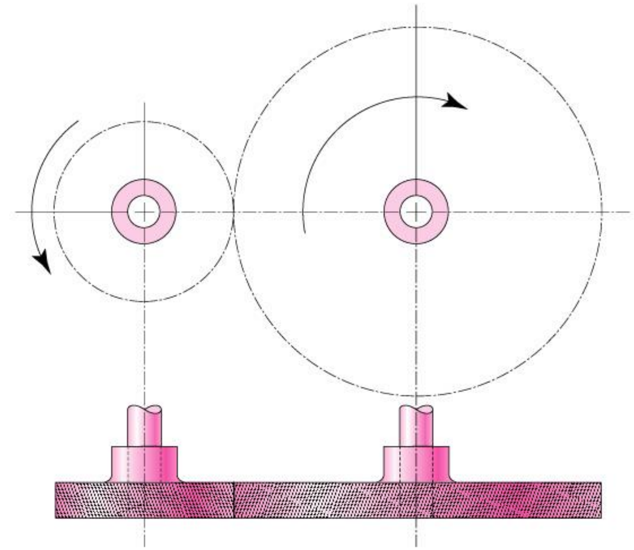

Fig. 13.2 Helical gears have teeth inclined to the axis of rotation. Sometimes helical gears are used to transmit motion between nonparallel shafts.

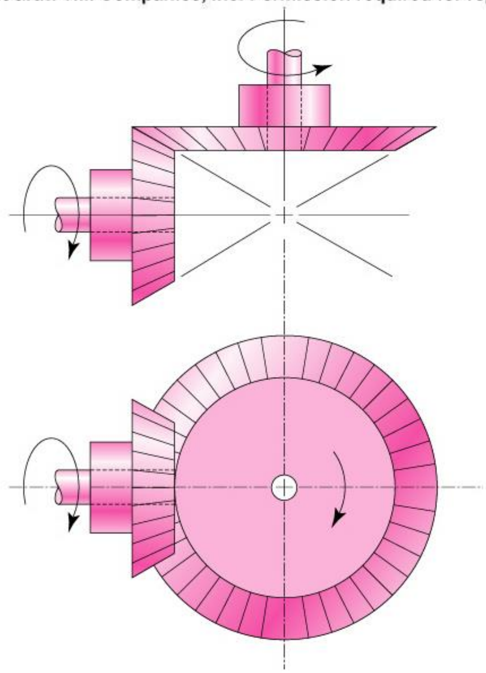

Fig. 13.3 Bevel gears have teeth formed on conical surfaces and are used mostly for transmitting motion between intersecting shafts.

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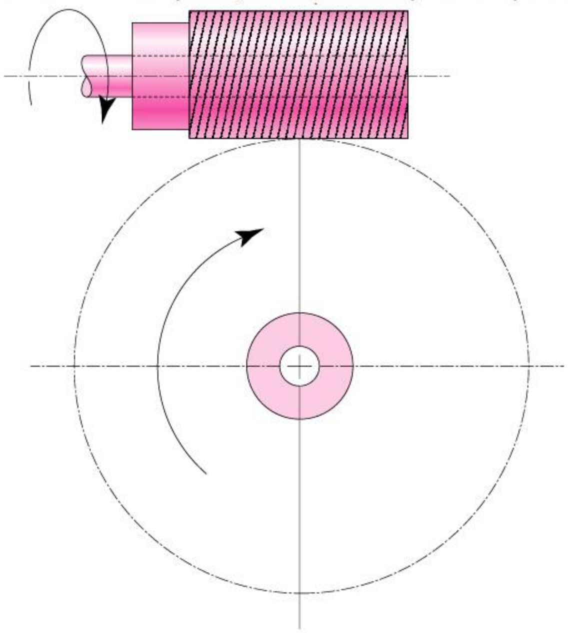
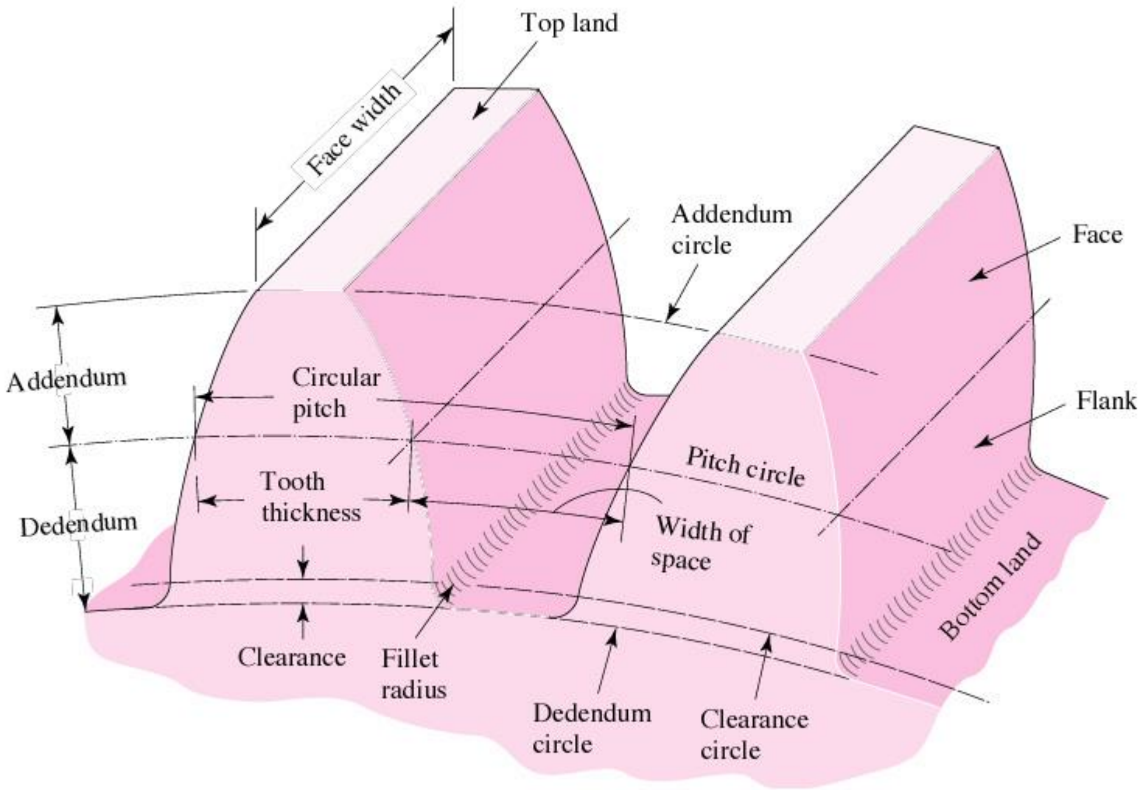


Fig. 13.4 Hypoid gears, worm gear are used to transmit motion between nonparallel, nonintersecting shafts.

Nomenclature



$P = N/d$

$p = \pi d/N = \pi m$

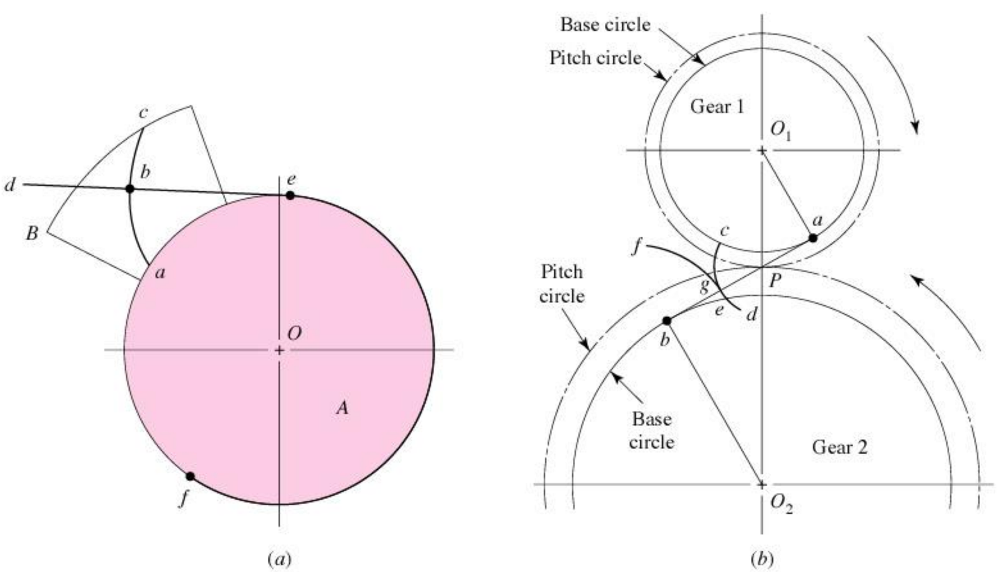
$m = d/N$

Fig. 13.5 Nomenclature. The circular pitch, p, is the distance, measured on the pitch circle, measured from a point on one tooth to a corresponding point on an adjacent point. The module, m, is the ratio of the pitch diameter to the number of teeth. The diametral pitch, P, is the ratio of the number of teeth on the gear to the pitch diameter. The addendum, a, is the radial distance between the top land and the pitch circle. The dedendum, b, is the radial distance from the bottom land to the pitch circle. The clerance circle is a circle that is tangent to the addendum circle of the mating gear.

Tooth Systems, Conjugate Action, Involute Properties

A *tooth system* is a standard which specifies the relationships involving addendum, dedendum, working depth, tooth thickness, and pressure angle.

When the tooth profiles are designed so as to produce a constant angular velocity ratio during meshing, these are said to have *conjugate action*. The *involute profile* is used to obtain the conjugate action.



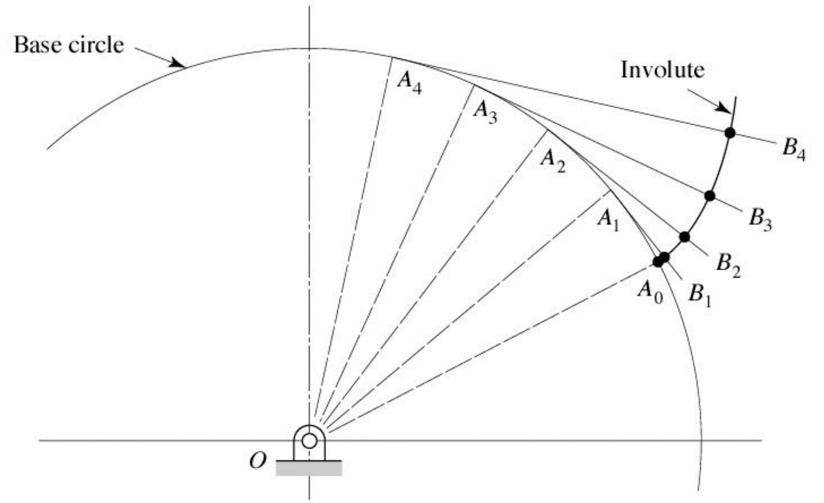


Fig. 13.8 Construction of an involute curve

Fig. 13.7 (a) Generation of an involute; (b) involute action

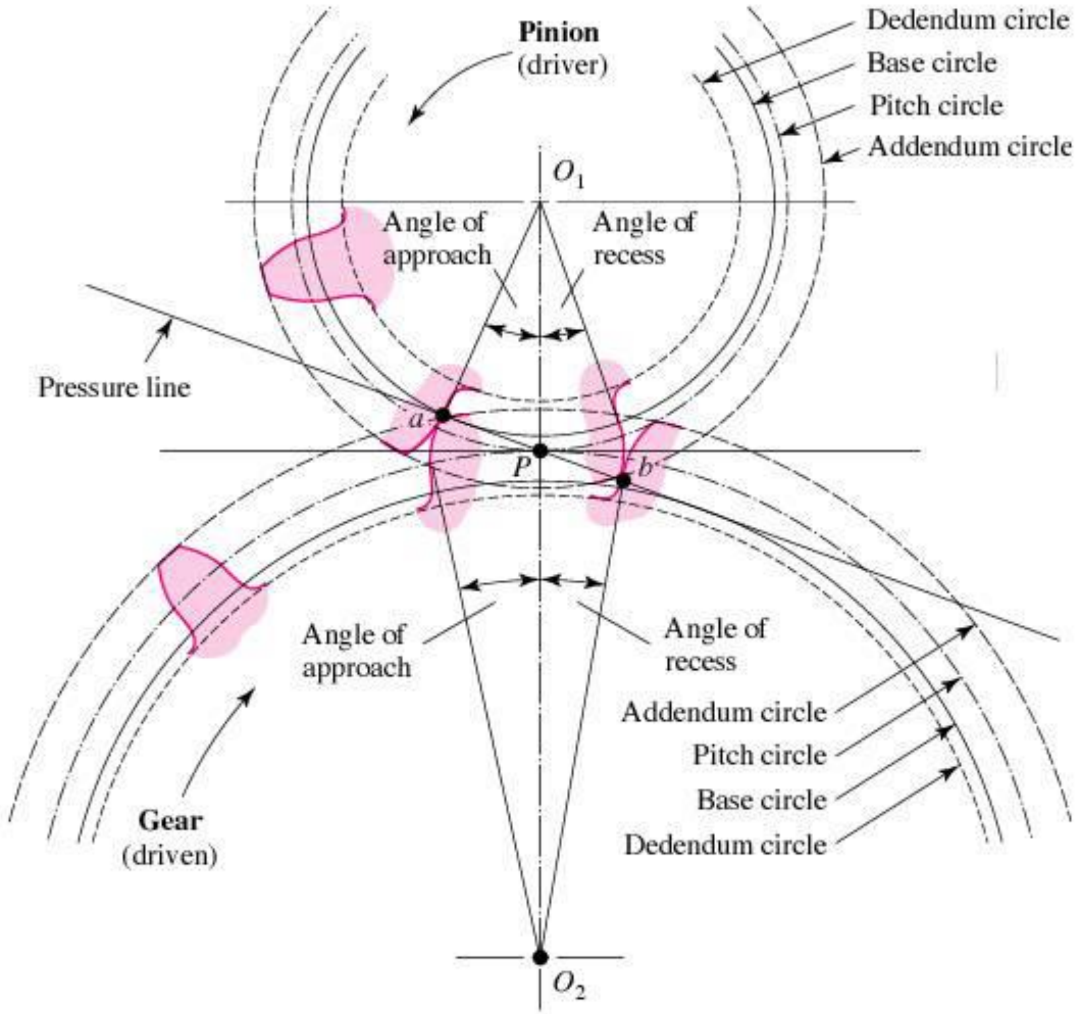


Fig. 13.12 Tooth action.

The Forming of Gear Teeth

There are a large number of ways of forming of the teeth of gears, such as sand casting, shell Molding, investment casting, permanent-mold casting, die casting, and centrifugal casting. Teeth can be formed by using the powder-metallurgy process; or by using extrusion. Gears which carry large loads in comparison with their size are usually made of steel and are cut with either form cutters or generating cutters.

Fig. 13.17 Generating a spur gear with a pinion cutter.

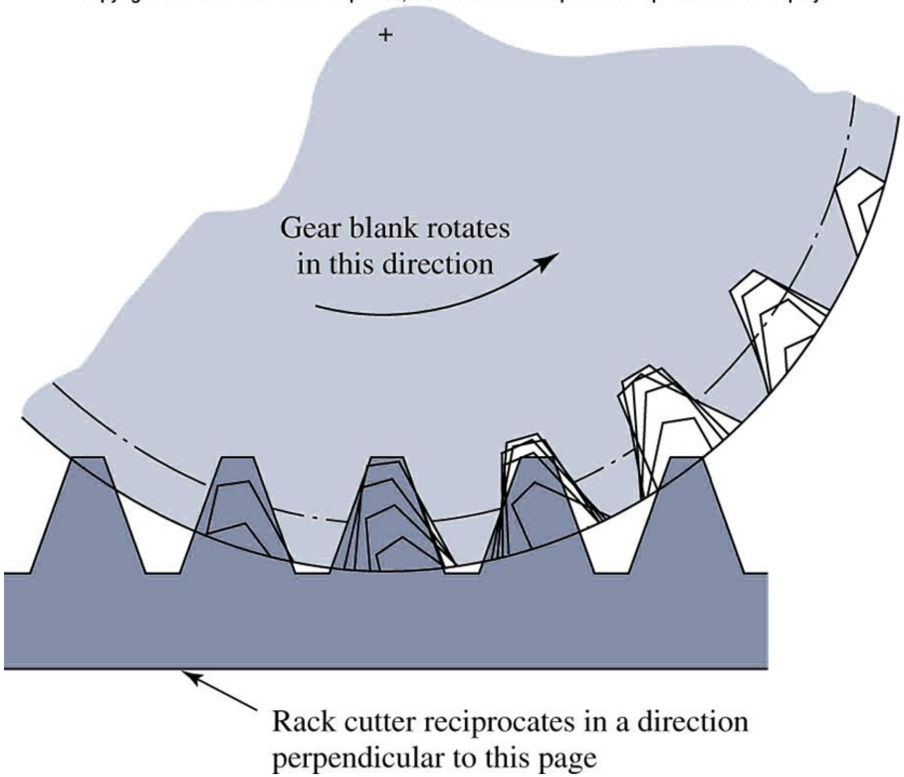


Fig. 13.18 Shaping teeth with a rack.

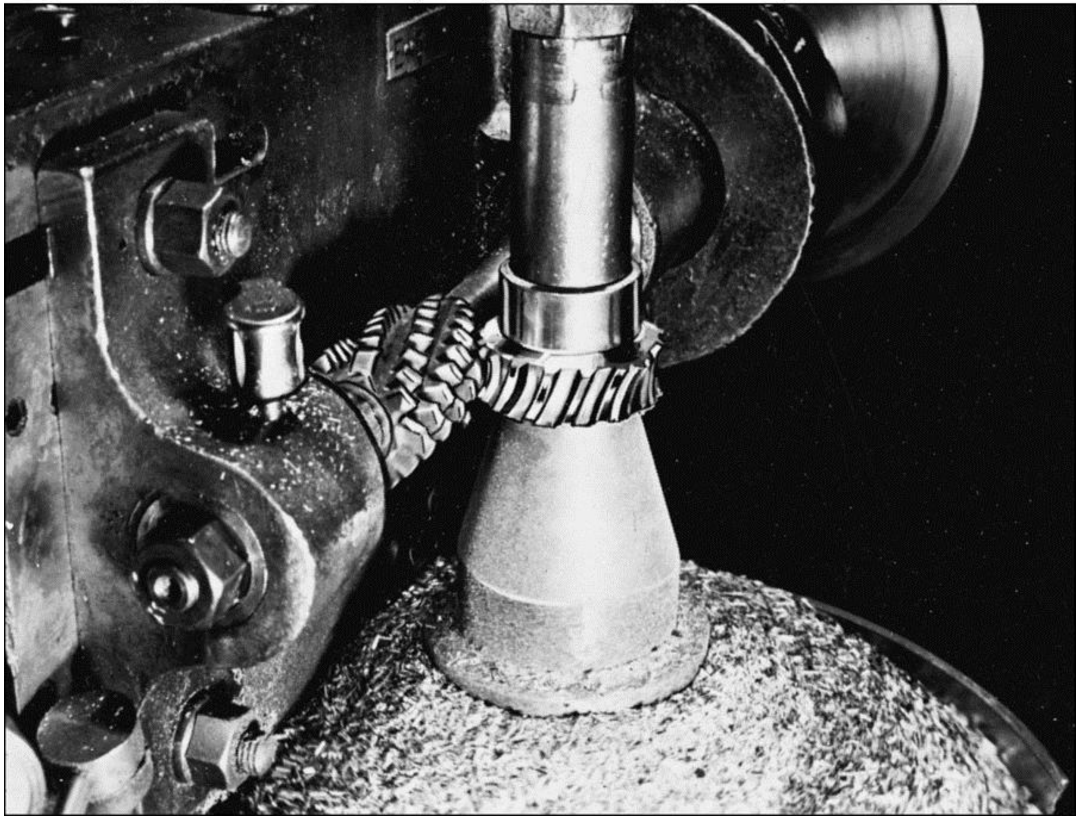


Fig. 13.19 Hobbing a worm gear.

The hob is simply a cutting tool which is shaped like a worm.

Choose an appropriate module, m (use fatigue, fracture mechanics, strength of materials relations, and standard sizes).

Calculate addendum and dedendum ($a=1.m$ $b=1.2 \sim 1.25$ m)

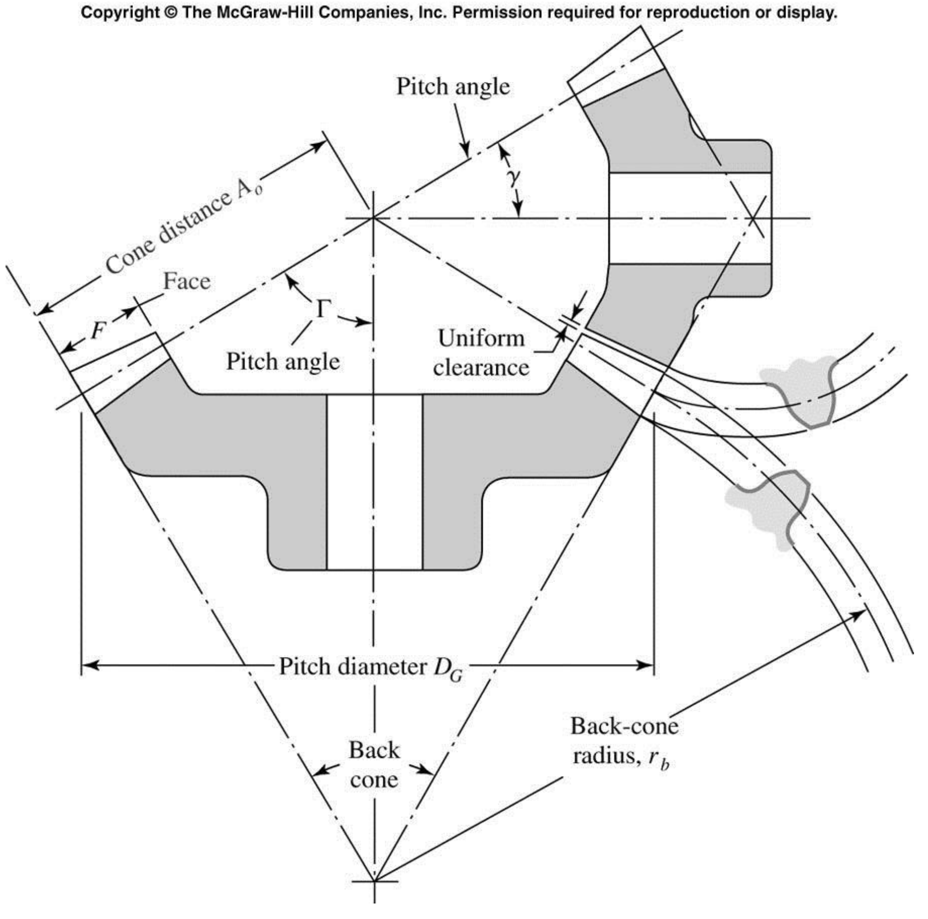
Calculate the pitch diameter, d, and the diameters of addendum and dedendum circles, d_a and d_b.

($d=N.m$ $d_a=d+2.a$ $d_b=d-2.5$ m)

Calculate the distance between the axes ($(dP+dG)/2 = m(N_P+N_G)/2$).

Calculate the face width, $F=F_w.p=F_w.\pi.m$.

Straight Bevel Gears



$\tan\gamma = N_P/N_G$

$\tan\Gamma = N_G/N_P$

$$N' = \frac{2\pi r_b}{p}$$

Fig. 13.20 Terminology of bevel gears.

Parallel Helical Gears

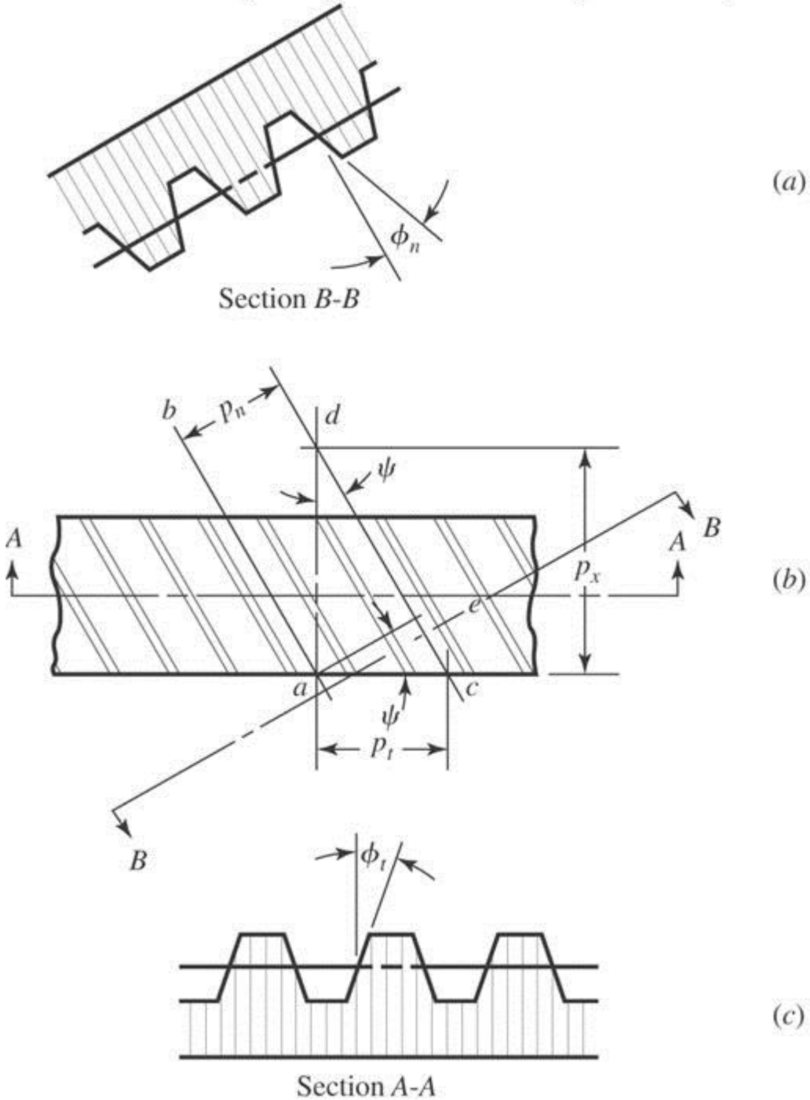
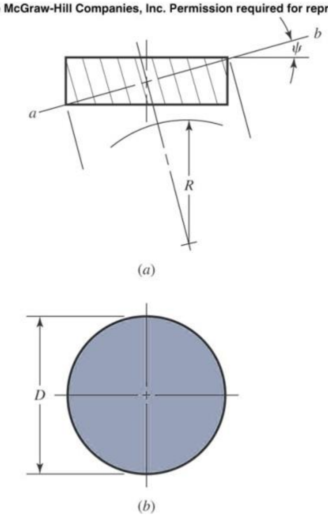


Fig. 13.22 Nomenclature of helical gears.

$$p_n = p_t \cos\psi \qquad p_x = \frac{p_t}{\tan\psi}$$

$$p_n = \pi m_n \qquad m_n = m_t \cos\psi$$

$$\cos\psi = \frac{\tan\phi_n}{\tan\phi_t}$$



$$N' = \frac{N}{\cos\phi}$$

Fig. 13.23 A cylinder cut by an oblique plane.

Worm Gears

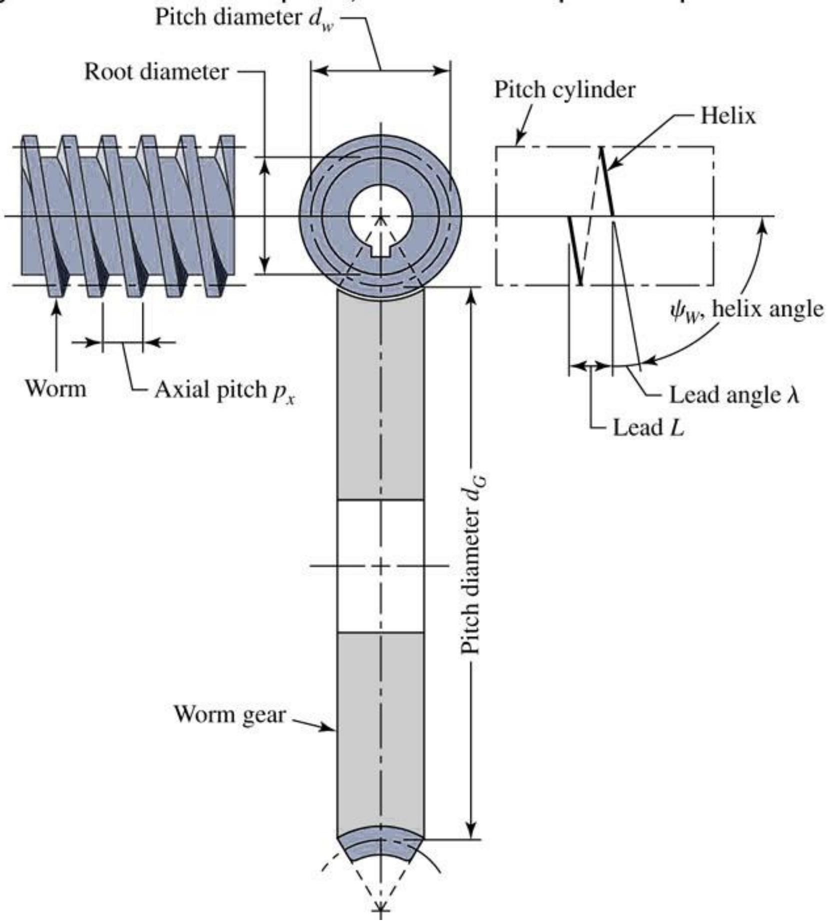


Fig. 13.24 Nomenclature of a single-enveloping worm gearset.

$d_G = N_G p_t / \pi$

$L = p_x N_W$

$\tan\lambda = L / \pi d_W$

$C^{0.875}/3 \leq d_W \leq C^{0.875}/1.7$

C : center distance

Gear Trains

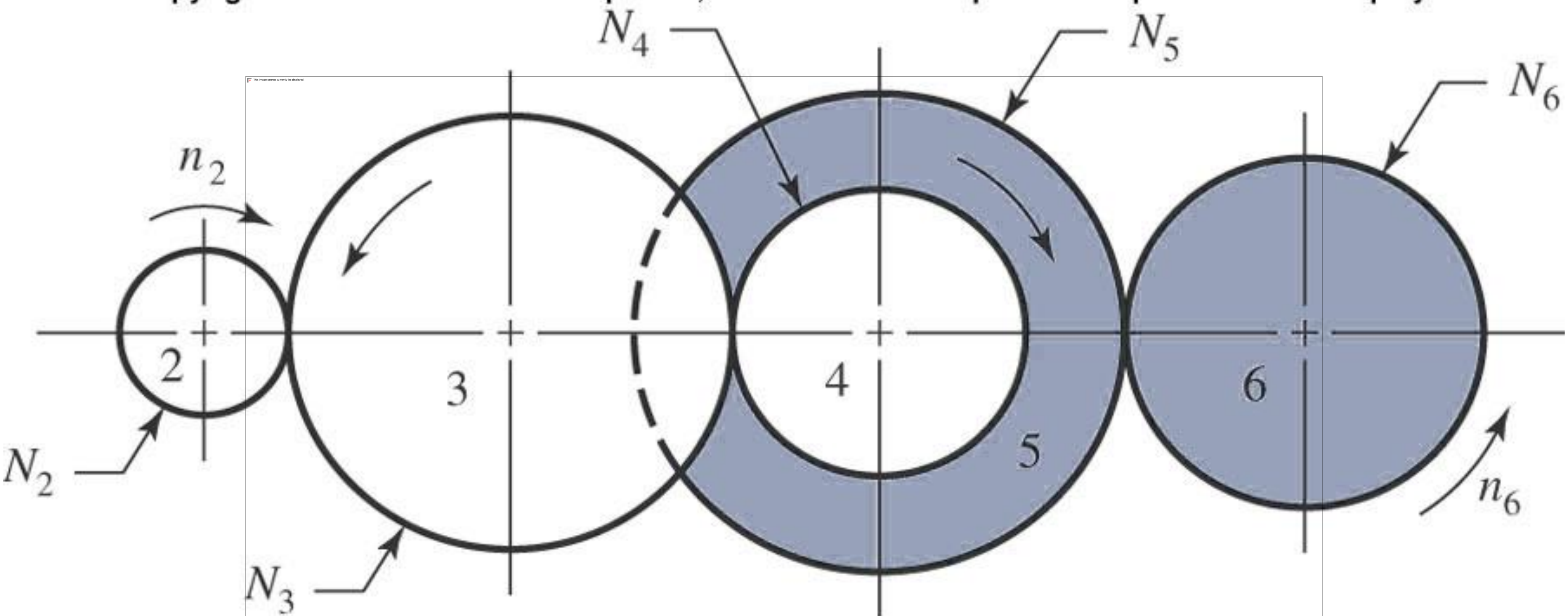


Fig. 13.27 Gear trains. Gear 3 is an idler. 2,3,5 are drivers. 3,4,6 are driven members.

$n_3=|N_2/N_3|n_2=|d_2/d_3|n_2$

$n_6=(N_2/N_3)\ (N_3/N_4)\ (N_5/N_6)n_2$

e=product of driving tooth numbers / product of driven tooth numbers, $n_L=en_F$

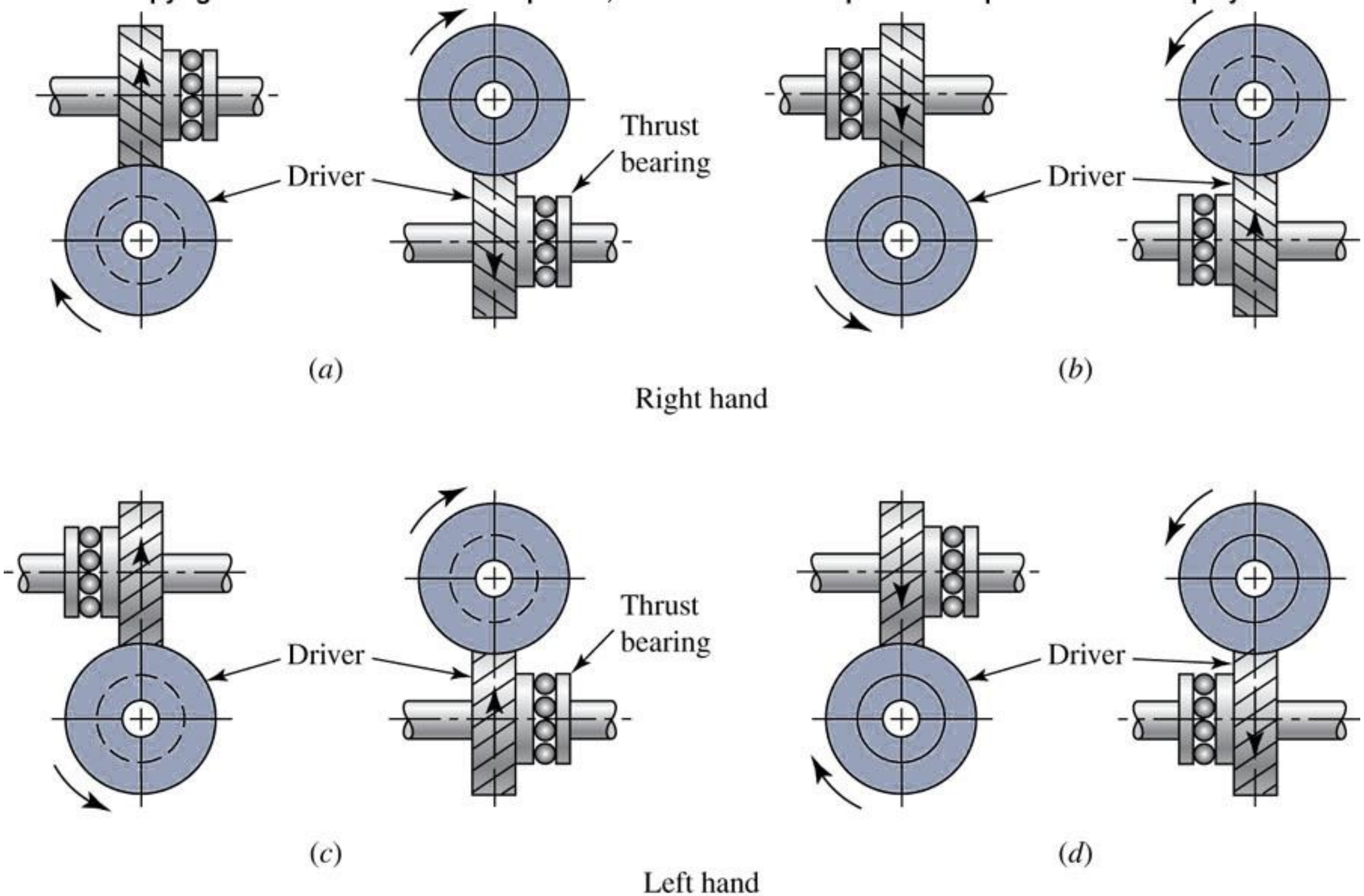


Fig. 13.26 Thrust, rotation, and hand relations for crossed helical gears.

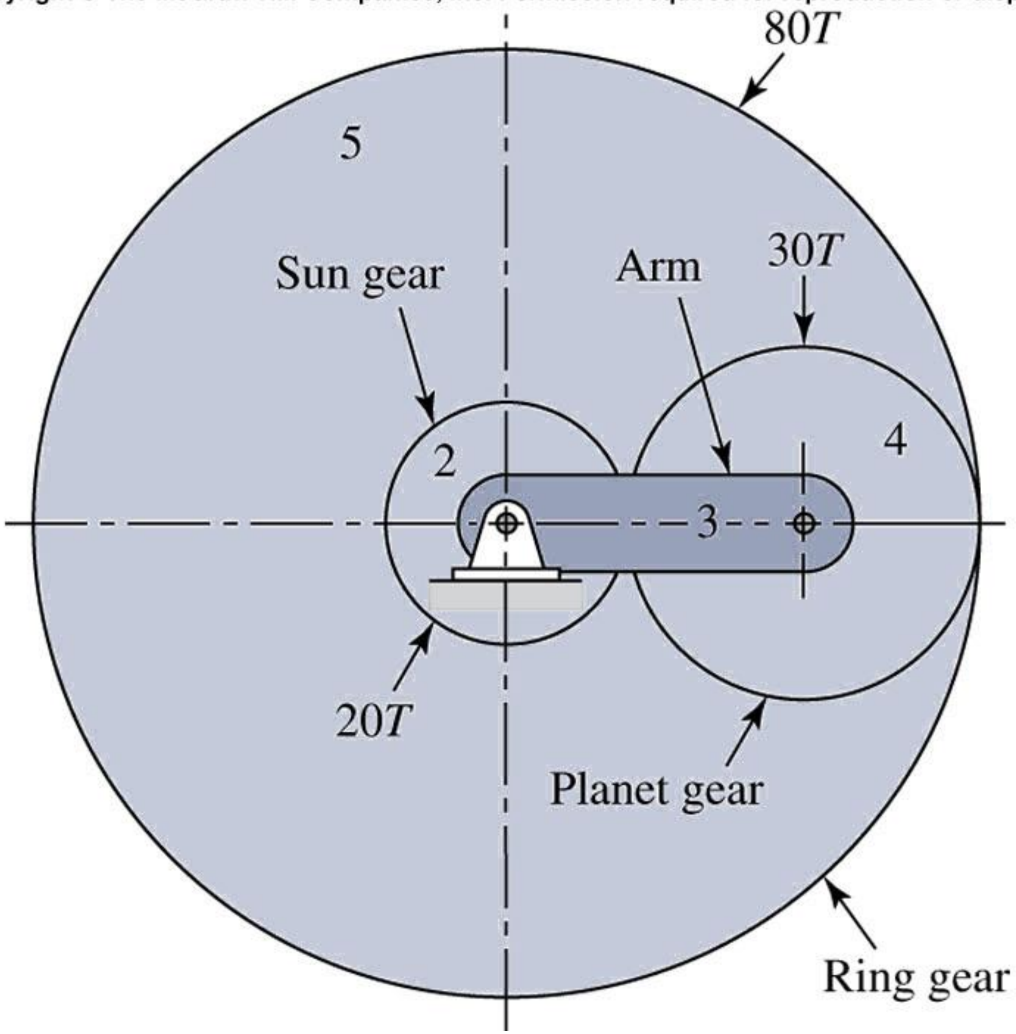


Fig. 13.28 Planetary, or epicyclic, gear trains. Some of the gear axes rotate about others.

$e=(n_L-n_A)/(n_F-n_A)$

Fig. 13.29

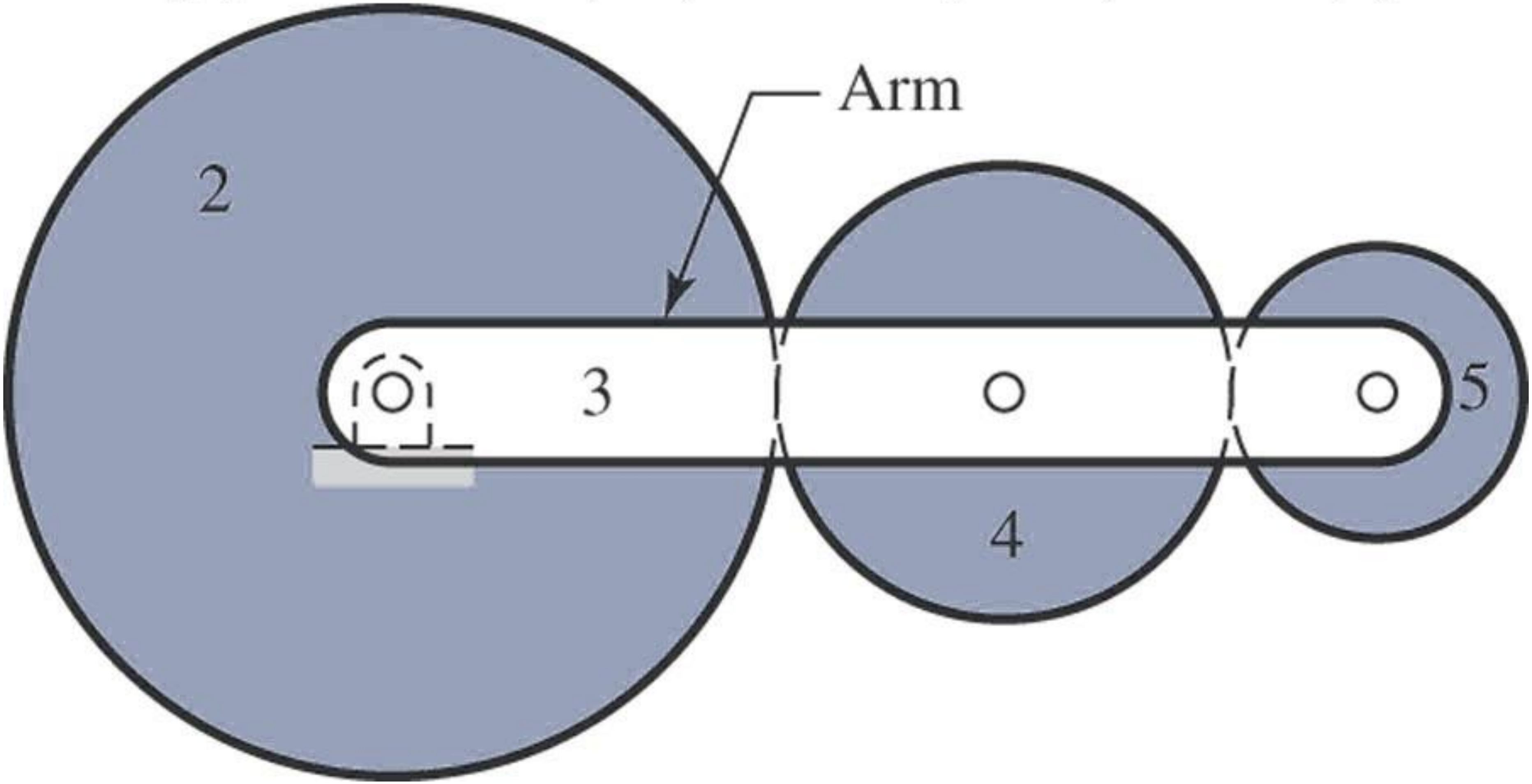
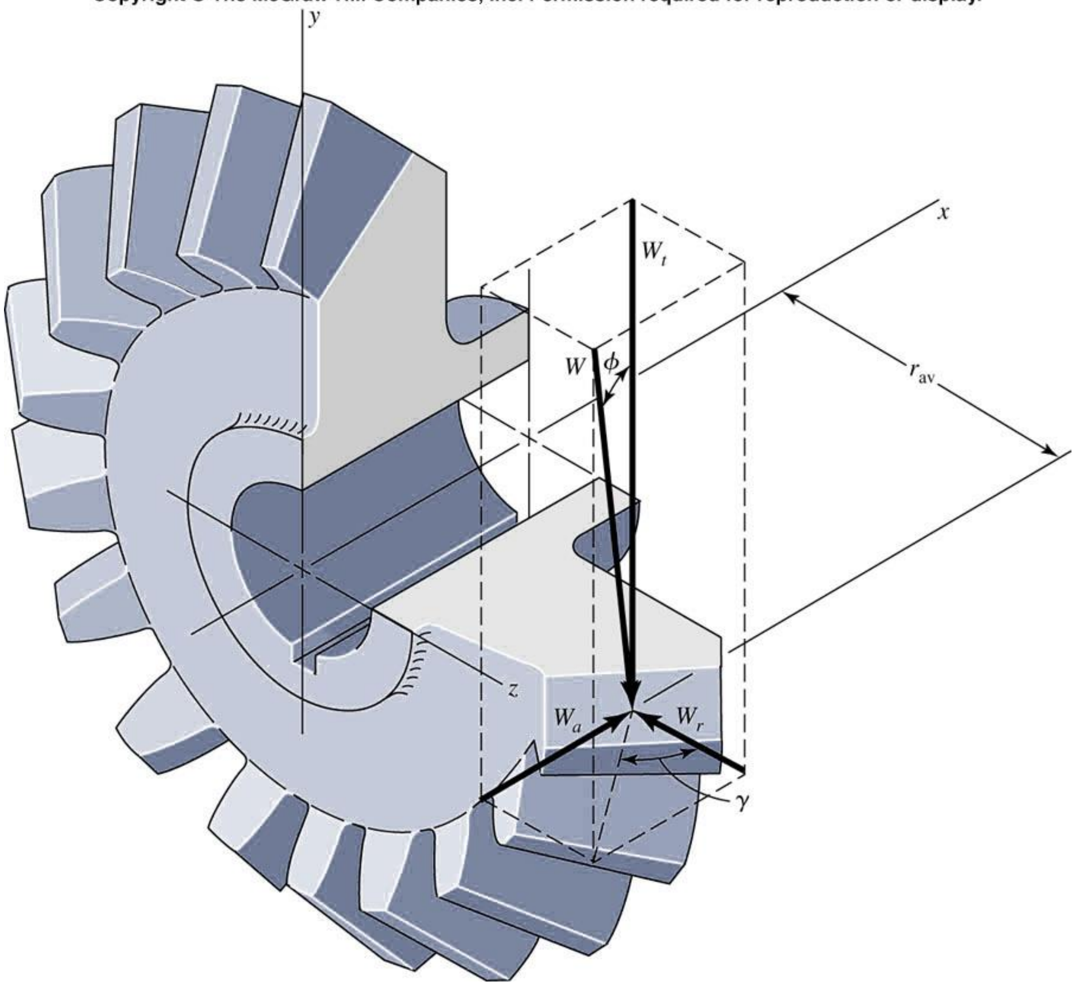


Fig. 13.35



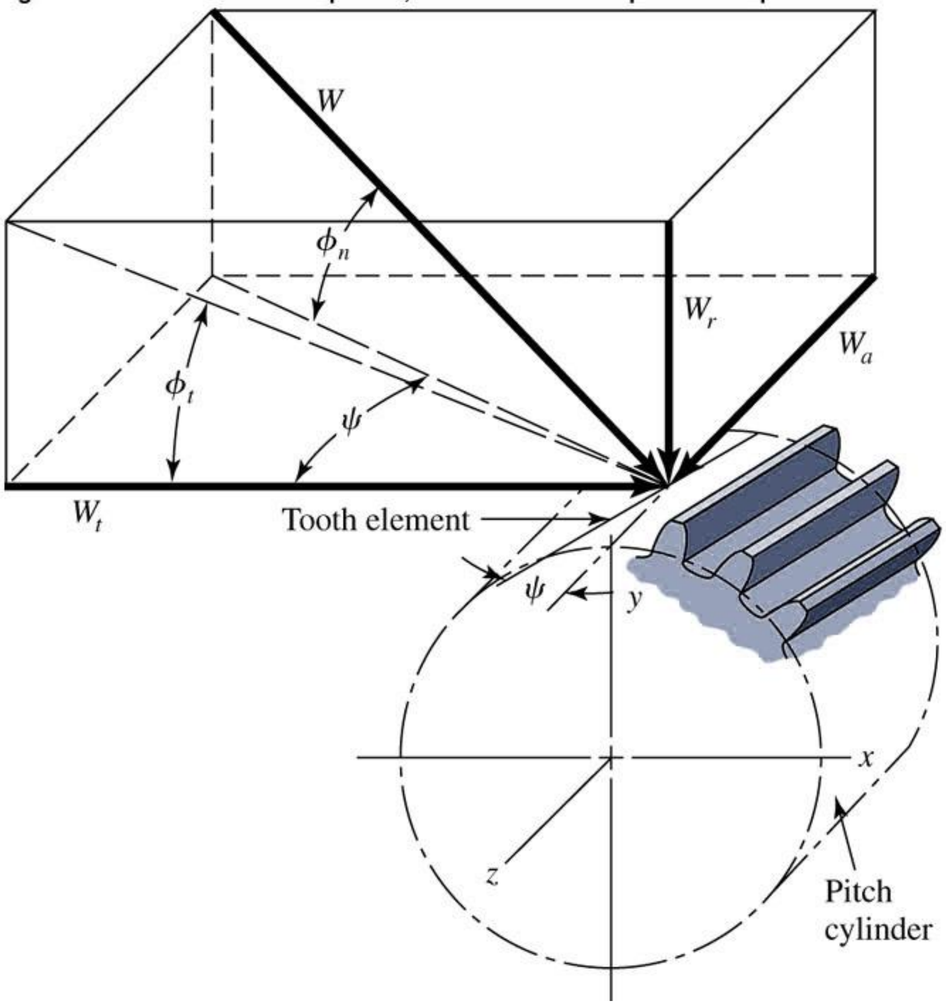
Force analysis

$W_t = T/r_{av}$

$W_r = W_t \tan\Phi \cos\gamma$

$W_a = W_t \tan\Phi \sin\gamma$

Fig. 13.37



$T_1 = W_t d_1 / 2$

<u>Spur gears</u>

$W_r = W.\sin\Phi_t$

$W_t = W.\cos\Phi_t$

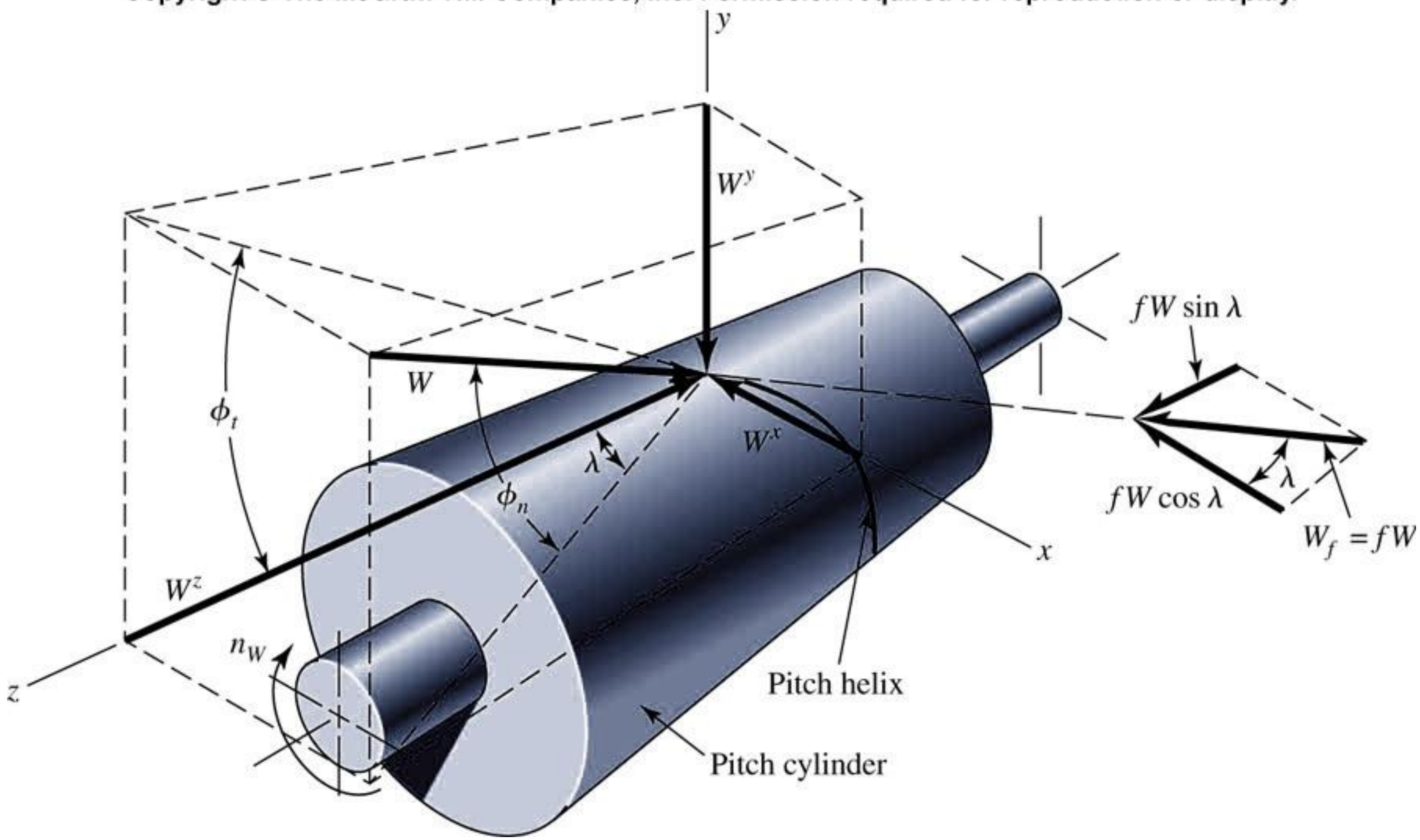
<u>Helical gears</u>

$W_r = W.\sin\Phi_n$

$W_t = W.\cos\Phi_n.\cos\psi$

$W_a = W.\cos\Phi_n.\sin\psi$

Fig. 13.40



$W^x = W\cos\Phi_n \sin\lambda$

$W^y = W\sin\Phi_n$

$W^z = W\cos\Phi_n \cos\lambda$

$W_{Wt} = -W_{Ga} = W^x$

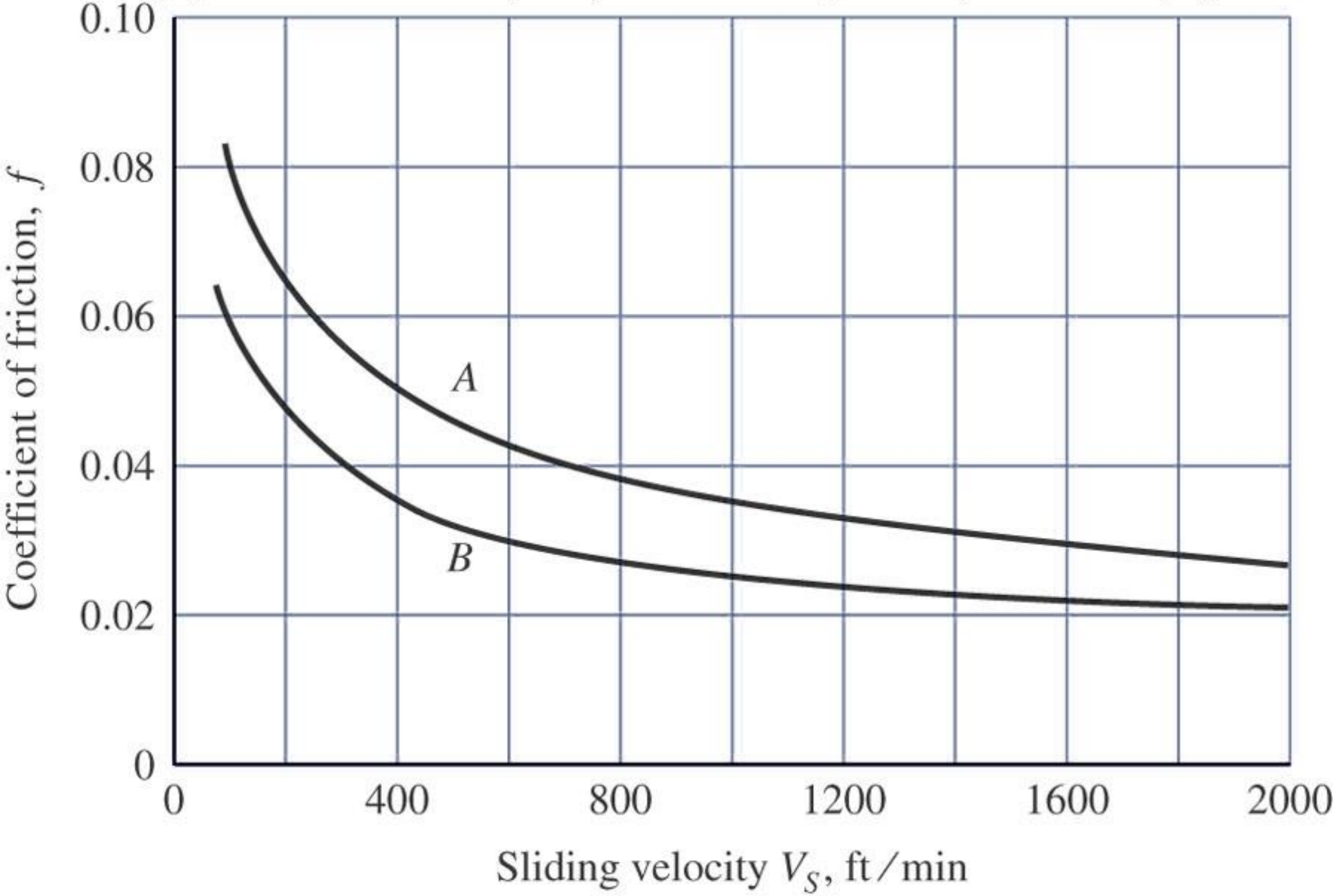
$W_{Wr} = -W_{Gr} = W^y$

$W_{Wa} = -W_{Gt} = W^z$

Efficiency

$\eta = (\cos\Phi_n - f\tan\lambda)/(\cos\Phi_n + f\cot\lambda)$

Fig. 13.42


0.10
0.08
0.06
0.04
0.02
0
Coefficient of friction, f
A
B
0
400
800
1200
1600
2000
Sliding velocity V_S, ft/min

Chapter 13, Problem 2.

A 15-tooth spur pinion has a module of 3 mm and runs at a speed of 1600 rev/min. The driven gear has 60 teeth. Find the speed of the driven gear, the circular pitch, and the theoretical center-to-center distance.

Chapter 13, Problem 13.

A parallel-shaft gearset consists of an 18-tooth helical pinion driving a 32-tooth gear. The pinion has a left-hand helix angle of 25°, a normal pressure angle of 20°, and a normal module of 3 mm. Find:

(*a*) The normal, transverse, and axial circular pitches

(*b*) The transverse module and the transverse pressure angle

(*c*) The pitch diameters of the two gears

Chapter 13, Problem 16.
The mechanism train shown consists of an assortment of gears and pulleys to drive gear 9. Pulley 2 rotates at 1200 rev/min in the direction shown. Determine the speed and direction of rotation of gear 9.

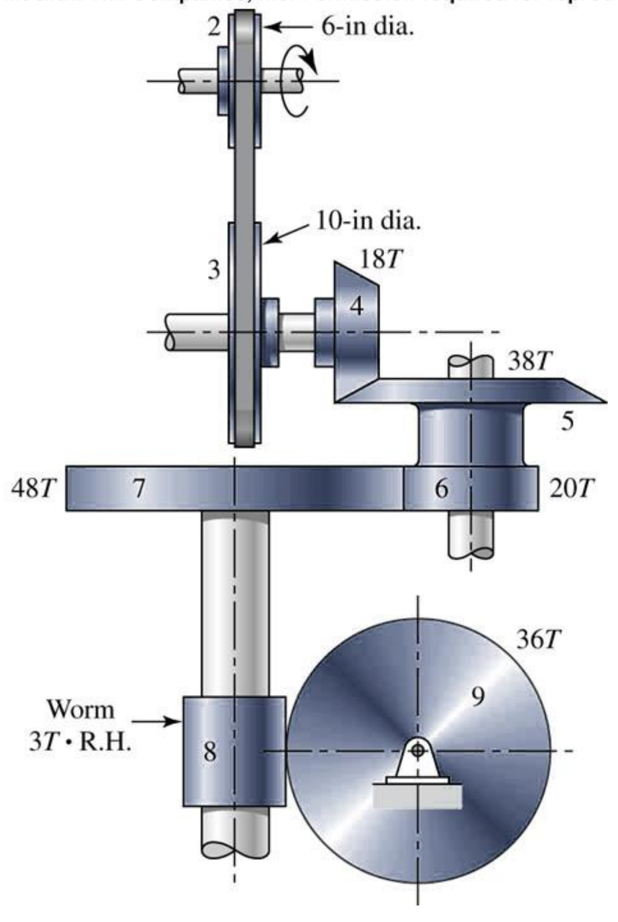


Figure P13-16

Chapter 13, Problem 21 (Chapter 13, Problem 21).

Tooth numbers for the gear train shown in the figure are $N2 = 12$, $N3 = 16$, and $N4 = 12$. How many teeth must internal gear 5 have? Suppose gear 5 is fixed. What is the speed of the arm if shaft *a* rotates counterclockwise at 320 rev/min?

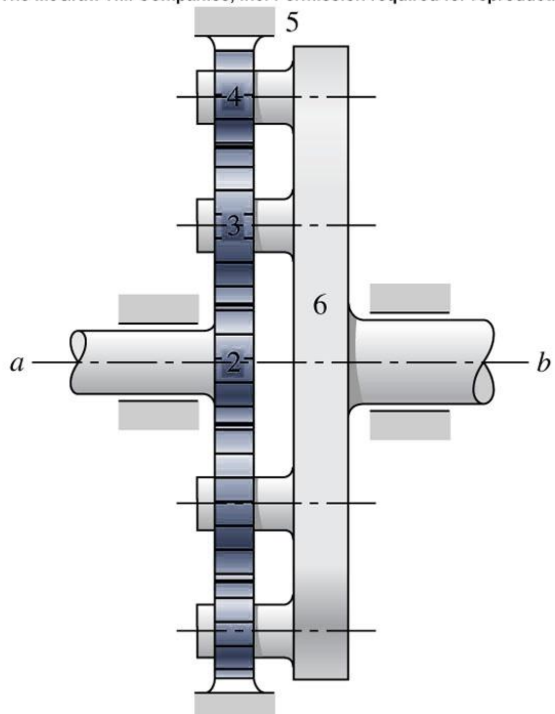


Figure P13-21

Chapter 13, Problem 24 (Chapter 13, Problem 25).

The epicycle train shown in the figure has the arm attached to shaft *a*, and sun gear 2 to shaft *b*. Gear 5, with 111 teeth, is an internal gear and is part of the frame. The two planets, gears 3 and 4, are both fixed to the same planet shaft. If this train is used as an in-line speed reducer, which is the input shaft, *a* or *b*? Will both shafts then rotate in the same or in the opposite directions?

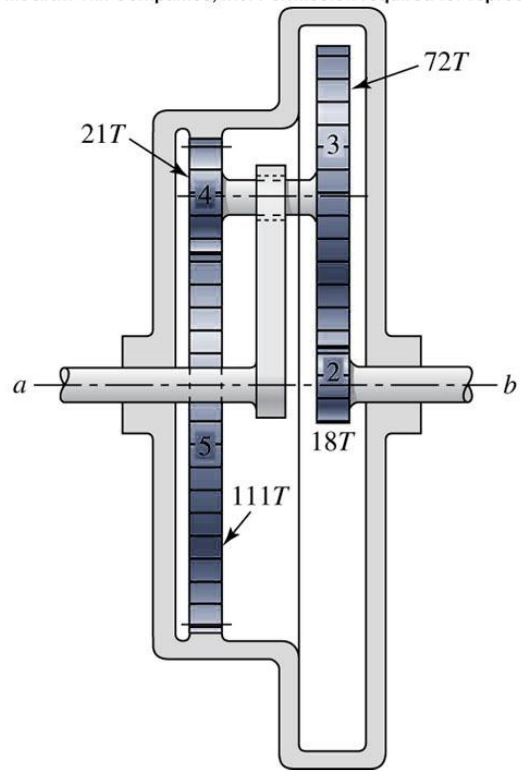


Figure P13-24

Choosing module (m) according to failure criteria

- Pitting is a surface fatigue failure due to many repetitions of high contact stresses

$$m_n = 0.9 \sqrt[3]{\frac{K_A \cdot K_V \cdot T_1 \cdot E \cdot (e+1)\cos^4\psi}{N_1^2 \cdot P_{em}^2 \cdot e \cdot \varepsilon_\alpha \, F_W}} \quad (mm)$$

- Fracture of a tooth

$$m_n = 0.6 \cdot \sqrt[3]{\frac{K_A \cdot K_V \cdot T_1 \cdot \gamma \cdot \cos\psi}{N_1 \cdot \sigma_{em} \cdot \varepsilon_\alpha \cdot F_W}} \quad (mm)$$

ε_α : profile ratio

K_A : Impact or contact load factor

K_V : Dynamic load factor

T_1 : Torque on pinion (N.mm)

N_1 : Number of teeth of pinion

γ : Form factor

$e = \frac{\omega_1}{\omega_2} = \frac{N_2}{N_1}$

E : Young's modulus (N/mm^2)

σ_{em} : Tensile (bending) strength (N/mm^2)

P_{em} : Hertz pressure (N/mm^2) (to resist pitting)

K_A : 1 – 2.25 (depending on the impact loads during the operation of machine)

K_V : It is chosen based on the Table 1.

Table 1. Dynamic load factor

Tangential velocity (m/s)	2	4	12	20	40	60
High quality	1	1	1.1	1.15	1.2	1.25
Normal quality	1	1.1	1.25	1.3	-	-
Pure quality (casting)	1.5	2.0	-	-	-	-

Table 2. Form factor (γ) for (ϕ_n=20°).

N′	13	14	15	16	18	20	30	50	100
γ	9.5	9.3	9.0	8.8	8.4	8.1	7.5	6.8	6.3

Table 3. Profile ratio (ε_α)

ψ=0	15°	30°	45°
1.73	1.65	1.41	1.05

Table 4. Width ratio (F_w=b/p_n)

Gears made of cast materials	2
Pure quality gears	3 ... 4
High quality gears	5 ... 8
Very high quality gears	9 ... 14

Material		σ_{em} [N/mm^2]	P_{em} [N/mm^2]
Cast Iron	GG20	35-45	220
	GG25	48-55	270
	GG30	60	330
Nodular Cast Iron	Ferritik	145	300
	Perlitik	145	400
Cast Steel	GS45	80	250
	GS52	90	310
	GS60	100	390
Tool Steel	St42	90-100	280-340
	St50	110-125	340-400
	St60	125-140	380-500
	St70	140-160	440-570
Tempered Steel	C22	120	330
	C45	135-150	450
	C60	150-165	500
	34Cr4	180-200	600
	37MnSi5	190-200	550
	42CrMo4	200	630
	35NiCr18	200	900
Case Hardening Steel	C10	100-115	1350
	C15	110-125	1500
	16MnCr5	190-210	1500
	20MnCr5	210-230	1500
	13Ni6	150	1350
	15CrNi6	200-220	1500
	13NiCr18	220	1400
	18CrNi8	210-230	1500
Hardened Steel	C60	160	1050
	Ck45	180	1350
	Ck53	220	1400
	37MnSi5	200	1250
	53MnSi4	200	1400
	41Cr4	200	1300
	50CrV4	240	1400
	42CrMo4	210	1500
Cyanide Hardening Steel	41Cr4	190	1350
	37MnSi5	200	1250
	35NiCr18	220	1350
	34Cr4	210	1200
	42CrMo4	240	1200
Nitrogen Hardening Steel	C45	160	750
	16MnCr5	170	720
	42CrMo4	290	850
	16MnCr5	210	880

Table 13–6

Maximum Tooth Numbers on Gears to Avoid Interference. Numbers Are Based on a Normal Pressure Angle of $\phi_n = 20°$ and Full-Depth Teeth. For Spur Gears, $\psi = 0$

Source: R. Lipp, "Avoiding Interference in Gears," *Machine Design*, vol. 34, no. 1, 1982, p. 122.

Number of Pinion Teeth, N_P	Number of Gear Teeth, N_G — Helix angle, ψ, deg: 0	5	10	15	20	25	30	35
8								12
9							12	34
10						12	26	∞
11					13	23	93	
12			12	16	24	57	∞	
13	16	17	20	27	50	1385		
14	26	27	34	53	207			
15	45	49	69	181	∞			
16	101	121	287	∞				
17	1309	∞	∞					

Note: The minimum number of teeth for the gear is N_P.