A FORMULA BOOK

FOR

DESIGN OF MACHINE MEMBERS

Principles of Designing Machine Elements
Under
Steady and Fatigue Loads

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FAILURE UNDER STATIC LOADS
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General Design Equation for Ductile Failure

$$n = S_{ys}/\tau_{\max}$$

Maximum Shear Stress Theory

$$n = 0.5\,Syt/\tau_{\max}$$

Maximum Distortion Energy Theory

$$n = S_{yt}/\sigma_e$$

$$\sigma_e = \left[(\sigma_1)^2 - \sigma_1\sigma_2 + (\sigma_2)^2\right]^{1/2}$$

Von-Mises Theory

$$\therefore n = 0.577\,S_{yt}/\tau_{\max}$$

Ductile Coulomb Mohr Theory

$$n = S_{ys}/\tau_{\max}$$

Maximum Normal Stress Theory (MNST)

$$n = S_{ut}/\sigma_1$$

$$n = S_{ut}/\sigma_1$$

$$n = S_{uc}/\sigma_2$$

$$n = S_{uc}/\sigma_2$$

Brittle Coulomb Mohr Theory (BCMT)

$$n = {S_{ut}}/{\sigma_1} + {S_{uc}}/{\sigma_2}$$

Modified I-Mohr Theory (M1MT)

$$n = S_{ut}/\sigma_1$$

$$\frac{1}{n} = \left[\frac{(S_{uc} - S_{ut}).\sigma_1}{S_{ut}.S_{uc}}\right] + \frac{\sigma_2}{S_{uc}}$$

Modified II-Mohr Theory (M2MT)

$$n = S_{ut}/\sigma_1$$

$$\frac{n\sigma_1}{S_{ut}} + \left[\frac{(n\sigma_2 + S_{ut})}{(S_{ut} - S_{uc})}\right]^2 = 1$$

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FAILURE UNDER FATIGUE LOADING
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10^3-Cycle Strength for Ductile Materials

Bending: $S_{10^3} = 0.9S_{ut}$

Axial: $S_{10^3} = 0.75S_{ut}$

Torsion: $S_{10^3} = 0.9S_{us}$

Steel $S_{us} = 0.8S_{ut}$

Others $S_{us} = 0.7S_{ut}$

Modifying Factors for Endurance Limits

$$S_e - k_a k_b k_c k_d k_e k_f$$

Surface factor, k_a

$$k_a = aS_{ut}^b$$

Table 1: Parameters for Marin Surface Modification Factor

Surface Finish	Factor *a*	Exponent *b*
Ground	1.58	- 0.085
Machined or Cold Drawn	4.51	- 0.265
Hot Rolled	57.70	- 0.718
As-Forged	272.00	- 0.995

Size factor, k_b for Bending and Torsion

k_b. = 1.00 for d ≤2.8

k_b. = 1.24 $d^{-0.107}$ for 2.8 < d ≤ 50 mm

k_b. = 1.51 $d^{-0.157}$ for 50 < d ≤ 250 mm

Load factor, k_c

Bending, $k_c = 1.0$

Axial, $k_c = 0.85$

Torsional, $k_c = 0.577$

Reliability Factor, k_e

Table 2: Reliability Factors

Reliability (%)	50	90	95	99	99.9
Factor, k_e	1.000	0.897	0.868	0.814	0.753

Modified Goodman Criterion:

$$1/FS = {\sigma_m}/{S_{ut}} + {\sigma_a}/{S_e}$$

Langer Yield Criterion

$$1/FS = {\sigma_m}/{S_{yt}} + {\sigma_a}/{S_{yt}}$$

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DESIGN OF SHAFT
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Shaft Torque: $T = 7124\,P/n$

Forces exerted on Shafts

Spur Gear:

$$W_t = 2T/D$$

$$W_r = W_t \tan\phi$$

Helical Gear:

$$W_r = W_t \frac{\tan\phi_n}{\cos\psi}$$

$$W_a = W_t \tan\psi$$

Chain Sprocket:

$$F_C = 2T/D$$

$$F_{Cx} = F_C\cos\theta \quad and \quad F_{Cy} = F_C\sin\theta$$

V-belt Sheaves::

$$F_N = 2T/D$$

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$F_B = 1.5F_N = 3T/D$

Flat-belt Pulleys: The analysis of the bending

$F_B = 2.0F_N = 4T/D$

Shaft diameter

$$D = \left[\frac{32N}{\pi}\sqrt{\left(\frac{K_t M}{S'n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_Y}\right)^2}\right]^{1/3}$$

Shaft as Torsion Bar $\theta = \dfrac{Tl}{GJ}$

The critical speed $n_c = (30/\pi)\sqrt{(g/\delta_{st})}$

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DESIGN OF KEYS AND KEYWAYS

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Shear Failure $\tau_{xy} = F/A_{shear}$

Bearing Failure $\sigma_x = F/A_{bearing}$

Length $L = \dfrac{4TN}{DWS_y}$

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ROLLING CONTACT BEARINGS

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Load/Life Relationship

$L_2/L_1 = (P_1/P_2)^k$

Design life

$L_d = (C/P_d)^k (10^6)$

$L_d = (h)(rpm)(60\,\min/h).$

Basic dynamic load rating:

$C = P_d\left(L_d/10^6\right)^{1/k}$

$C = P_d\ f_L/f_N$

The equivalent load

$P = VR$

$V = 1.0$ if the inner race rotates

$V = 1.2$ if the outer race rotates

$P = VXR + YT$

$$P_A = 0.4F_{rA} + 0.5\frac{Y_A}{Y_B}F_{rB} + Y_A T_A$$

$$P_B = F_{rB}$$

$$P_A = 0.4F_{rB} + 0.5\frac{Y_B}{Y_A}F_{rA} - Y_B T_A$$

Life Prediction under Varying Loads

$$F_m = \left(\frac{\sum_i (F_i)^p N_i}{N}\right)^{1/p}$$

$$L = \left(C/F_m\right)^p$$

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DESIGN OF SPRINGS

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Helical Compression Springs

Diameters

$OD = D_m + D_w$

$ID = D_m - D_w$

Spring Rate: $k = \Delta F/\Delta L$

The pitch angle $\lambda = \tan^{-1}\left[p/\pi D_m\right]$

Installation Considerations:

$$OD_s = \sqrt{D_m^2 + \frac{p^2 - D_w^2}{\pi^2}} + D_w$$

Spring Index: $C = D_m/D_w$

Number of Coils:

Squared and ground ends $N_a = N - 2$

Plain ends $N_a = N$

Plain coils with ground ends $N_a = N - 1$

Pitch:

Squared and ground ends: $L_f = pN_a + 2D_w$

Squared ends only: $L_f = pN_a + 3D_w$

Plain and ground ends: $L_f = p(N_a + 1)$

Plain ends: $L_f = pN_a + D_w$

Coil Clearance: $cc = \dfrac{L_o - L_s}{N_a}$

Stresses $\tau = \dfrac{8KFD_m}{\pi D_w^3} = \dfrac{8KFC}{\pi D_w^2}$

The Wahl factor, $K = \dfrac{4C-1}{4C-4} + \dfrac{0.615}{C}$

Deflection: $\theta = \dfrac{TL}{GJ}$

The linear deflection,

$$f = \frac{8FD_m^3 N_a}{GD_w^4} = \frac{8FC^3 N_a}{GD_w}$$

Buckling $\dfrac{L_f}{D_m} = 8.0$

Extension springs

Bending stress $\sigma_A = \dfrac{16D_m F_o K_1}{\pi D_w^3} + \dfrac{4F_o}{\pi D_w^2}$

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$$K_1 = \frac{4C_1^2 - C_1 - 1}{4C_1(C_1 - 1)}$$

$$C_1 = 2R_1/D_w$$

Torsion stress

$$\sigma_A = \frac{8D_m F_o K_2}{\pi D_w^3}$$

$$K_2 = \frac{4C_2 - 1}{4C_2 - 4}$$

$$C_2 = 2R_2/D_w$$

Helical Torsion Springs

$$D_m = \frac{D_{m1} N_a}{(N_a + \theta)}$$

$$.L = D_w(N_a + 1 + \theta)$$

Stress

$$\sigma = \frac{McK_b}{I} = \frac{MK_b}{Z} = \frac{32MK_b}{\pi D_w^3}$$

$$K_b = \frac{4C^2 - C - 1}{4C(C-1)}$$

Deflection

$$\theta = \frac{10.2MD_m N_a}{ED_w^4}$$

$$k_\theta = \frac{ED_w^4}{10.2D_m N_a}$$

Number of coils

$$N_e = \frac{(L_1 + L_2)}{3\pi D_m}$$

$$N_a = N_b + N_e$$

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DESIGN OF JOINTS AND FASTENERS

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Welded Joints

Stresses

Direct tension or compression: $f = P/A_w$

Direct vertical shear: $f = V/A_w$

Bending: $f = M/Z_w$

Twisting: $f = Tc/J_w$

Fastener

Tightening Torque: $T = KDP$

Externally Applied Force on a Bolted Joint

$$F_b = P + \frac{k_b}{k_b + k_c} F_e$$

$$F_c = P - \frac{k_c}{k_b + k_c} F_e$$

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DESIGN OF POWER SCREWS

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Power Screws

The tensile stress area, A_t:

$$A_t = \frac{\pi}{4}\left[\frac{D_r + D_p}{2}\right]^2$$

Torque and Efficiency

$$T_u = \frac{FD_p}{2}\left[\frac{L + \pi f D_p}{\pi D_p - fL}\right]$$

$$T_u = \frac{FD_p}{2}\left[\frac{\tan\lambda + f}{1 - f\tan\lambda}\right]$$

$$T_u = \frac{FD_p}{2}\left[\frac{\cos\phi\tan\lambda + f}{\cos\varphi - f\tan\lambda}\right]$$

$$\tan\lambda = \frac{L}{\pi D_p}$$

$$T_d = \frac{FD_p}{2}\left[\frac{\pi f D_p - L}{\pi D_p + fL}\right]$$

$$T_d = \frac{FD_p}{2}\left[\frac{f - \tan\lambda}{1 + f\tan\lambda}\right]$$

$$T_d = \frac{FD_p}{2}\left[\frac{f - \cos\phi\tan\lambda}{\cos\phi + f\tan\lambda}\right]$$

$$e = \frac{T'}{T_u} = \frac{FL}{2\pi T_u}$$

Ball Screws

The load/life relationship

$$\frac{L_2}{L_1} = \left(\frac{P_1}{P_2}\right)^3$$

Torque and Efficiency

$$e = \frac{T'}{T_u} = \frac{FL}{2\pi T_u}$$

$$T_b = 0.43FL$$

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DESIGN OF BRAKES AND CLUTCHES

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Torque capacity

$$T = CPK/n$$

$$T = \frac{Wk^2(\Delta n)}{93.68t} N.m$$

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The term WK^2

$$WK^2 = 122000\,L\left(R_1^4 - R_2^4\right)$$

$$Wk_e^2 = Wk^2\left(n/n_c\right)^2$$

$$Wk_e^2 = W\left(\frac{V}{2\pi n}\right)^2$$

Energy Absorption

$$E = 5.6x10^{-4}WK^2n^2$$

Plate-Type Clutch

$$T_f = fNR_m$$

$$P_f = \frac{T_f n}{7124}hp$$

$$WR = \frac{P_f}{A}$$

WR==62hp/m^2 for frequent applications,
WR== 155hp/m^2 for average service
WR==620hp/m^2 for infrequently applications

Cone Clutch Brake

$$T_f = fNR_m = \frac{fR_mF_a}{\sin\alpha + f\cos\alpha}$$

Drum Brake

$$F_f = WL/\left(a/f - b\right)$$

$$T_f = \tfrac{1}{2}F_fD_d$$

Long Shoe Drum Brakes

$$T_f = r^2 fwp_{\max}\left(\cos\theta_1 - \cos\theta_2\right)$$

$$W = \left(M_N + M_f\right)/L$$

$$M_N = 0.25\,p_{\max}wrC\begin{bmatrix}2\left(\theta_1 - \theta_2\right)\\ -\sin 2\theta_2 + \sin 2\theta_1\end{bmatrix}$$

$$M_f = fp_{\max}wr\begin{bmatrix}r\left(\cos\theta_1 - \cos\theta_2\right)\\ +0.25C\left(\cos 2\theta_2 - \cos 2\theta_1\right)\end{bmatrix}$$

$$P_f = \frac{T_f n}{7124}hp$$

$$A = L_s w = 2wr\sin\left[\left(\theta_2 - \theta_2\right)\big/2\right]$$

$$WR = P_f\big/A$$

Band Brakes

$$T_f = \left(P_1 - P_2\right)r$$

$$P_2 = P_1/e^{f\theta}$$

P_1, $P_1 = P_{\max}rw$

$$W = P_2a/L$$

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DESIGN OF FLEXIBLE DRIVES

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V-Belt Drive

The belt speed, V_b

$$V_b = R_1\omega_1 = R_2\omega_2$$

$$V_b = \tfrac{1}{2}D_1\omega_1 = \tfrac{1}{2}D_2\omega_2$$

$$\omega_1/\omega_2 = D_2/D_1$$

Pitch length, L, center distance, C relationship

$$L = \begin{bmatrix}2C + 1.57\left(D_2 + D_1\right)\\ +\left(D_2 - D_1\right)^2/4C\end{bmatrix}$$

$$C = \left[B + \sqrt{B^2 - 32\left(D_2 - D_1\right)^2}\right]\Big/16$$

$$B = 4L - 6.28\left(D_2 + D_1\right)$$

Angle of contact

$$\theta_1 = 180^o - 2\sin^{-1}\left[\left(D_2 - D_1\right)/2C\right]$$

$$\theta_2 = 180^o + 2\sin^{-1}\left[\left(D_2 - D_1\right)/2C\right]$$

Chain Drives

Strand factors:

Two strands: Factor = 1.7
Three strands: Factor = 2.5
Four strands: Factor = 3.3

The chain length

$$L = \begin{bmatrix}2C + \frac{1}{2}\left(N_2 + N_1\right)\\ +\left(N_2 - N_1\right)^2/4\pi^2C\end{bmatrix}$$

The center distance

$$C = \tfrac{1}{4}\begin{bmatrix}L - \frac{1}{2}\left(N_2 + N_1\right) + \\ \sqrt{\left[L - \frac{1}{2}\left(N_2 + N_1\right)\right]^2 - \frac{8}{4\pi^2}\left(N_2 - N_1\right)^2}\end{bmatrix}$$

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DESIGN OF GEARS

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Spur Gear

Pitches

$$p = \pi D_P/N_P = \pi D_G/N_G$$

$$P_d = N/D = N_G/D_G = N_P/D_P$$

$$m = D_G/N_G = D_P/N_P$$

$$m = 25.4/P_d$$

Gear Features

$$c = b - a$$

$$D_o = \left(N + 2\right)/P_d \text{ or } D_o = m\left(N + 2\right)$$

$$D_R = D - 2b$$

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$h_t = a + b$

$h_k = a + a = 2a$

$h_t = h_k + c$

$t = p/2 = \pi/p_d$

Center Distance (C

$C = \frac{1}{2}(D_G + D_P)$ or $C = \frac{1}{2P_d}(N_G + N_P)$

or $C = \frac{m}{2}(N_G + N_P)$

Velocity Ratio

$VR = \frac{\omega_P}{\omega_G} = \frac{n_P}{n_G} = \frac{R_G}{R_P} = \frac{D_G}{D_P} = \frac{N_G}{N_P}$

$v_t = \pi D_P n_P/60 = \pi D_G n_G/60$

Loads on Gear

$W_t = 746 P/v_t$

$W_n = W_t/\cos\phi$

$W_r = W_t \tan\phi$

Stresses in Gear Teeth

$$\sigma_t = \left(\frac{W_t P_d}{FJ}\right)\left(\frac{K_a K_s K_m K_B}{K_v}\right)$$

$$\sigma_c = C_p\sqrt{(C_a C_s C_m/C_v)(W_t/FD_p I)}$$

Helical Gear

Pitches

$p = \pi N/D$

$p_n = p\cos\psi$

$P_d = N/D$

$P_{nd} = P_d/\cos\psi$

$P_x = p/\tan\psi = \pi/(P_d \tan\psi)$

Loads on Gear

$W_x = W_t \tan\psi$

$\tan\phi_n = \tan\phi_t \cos\psi$

$W_r = W_t \tan\phi_t$

$W_n = W_t/\cos\phi_n \cos\psi$

Bevel Gear

Pitches

$\gamma = \tan^{-1}(N_P/N_G)$

$\Gamma = \tan^{-1}(N_G/N_P)$

$P_d = N_P/d = N_G/D$

Geometrical Features

Whole depth	$h_t = 2.188/P_d + 0.002$
Working depth	$h_k = 2.000/P_d$
Clearance	$c = 0.188/P_d + 0.002$
Addendum: Gear	$a_G = \frac{0.54}{P_d} + \frac{0.460}{P_d(N_G/N_P)^2}$
Addendum: Pinion	$a_P = h_k - a_G$
Outside diameter: Gear	$D_o = D + 2a_G \cos\Gamma$
Outside diameter: Pinion	$d_o = d + 2a_P \cos\gamma$
Outer cone distance	$A_o = D/(2\sin\Gamma) = d/(2\sin\gamma)$
Preferred face width	$F = A_o/3$ or less (maximum $F = 10/P_d$)

Load on Gear

$W_{tP} = T/r_m$

$r_m = d/2 - (F/2)\sin\gamma$

$W_{rP} = W_{tP}\tan\phi\cos\gamma$

$W_{xP} = W_{tP}\tan\phi\sin\gamma$

$W_t = 14248 P/dn_P$

Stresses

$$\sigma_t = \left(\frac{W_t P_d}{FJ}\right)\left(\frac{K_a K_s K_m}{K_v}\right)$$

Worm Gearing

Pitches

$p = \pi D_G/N_G$

$P_d = N_G/D_G$

$P_d p = \pi$

Lead

$L = N_W P_x$.

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

$\tan\phi_n = \tan\phi_t \cos\lambda$

Loads on Gear

$T_o = 7124 P_o/n_G$

$T_o = W_{tG} r_G = W_{tG}(D_G/2)$

$W_{tG} = 2T_o/D_G$

$$W_{xG} = W_{tG}\left(\frac{\cos\phi_n \sin\lambda + \mu\cos\lambda}{\cos\phi_n \cos\lambda - \mu\sin\lambda}\right)$$

$$W_{rG} = \frac{W_{tG}\sin\phi_n}{\cos\phi_n\cos\lambda - \mu\sin\lambda}$$

$$W_f = \frac{\mu W_{tG}}{\cos\phi_n\cos\lambda}$$

Efficiency

$P_i = P_o + P_L$

$P_L = v_s W_f$

$\eta = P_o/P_i$

Stress in Worm Gear Teeth

$\sigma = W_d/(yFp_n)$

$W_d = W_{tG}/K_V$

$K_v = 6.1/(6.1 + v_{tG})$

$W_{tR} = C_s D_G^{0.8} F_e C_m C_v/75$

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FAILURE THEORIES
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Table 1: Recommended Factor of Safety

Stress Type	Material Condition	Environmental Condition	Recommended Design factor of safety
Very Certain	Ductile and Reliable Data	Well Controlled	1.25 to 1.5
Readily Determined	Ductile and Well Known	Reasonably Constant	1.5 to 2.0
Fairly Certain	Ductile and Common	Ordinary	2.0 to 2.5
Could Vary	Less Tried Ductile or Brittle	Average	2.5 to 3.0
Could Vary	Less Reliable Data	Average	3.0 to 4.0
Uncertain	Common	Uncertain	3.5 to 5.0

Table 2: Typical Properties of Gray Cast Iron

ASTM Number	Ultimate Tensile Strength S_{ut}, MPa	Ultimate Compressive Strength S_{uc}, MPa	Torsional Shear Strength, S_{us}, MPa	Endurance Limit S_e', MPa	Brinell Hardness, H_B
20	152	572	179	69	156
25	179	669	220	79	174
30	214	752	276	97	210
35	252	855	334	110	212
40	293	965	393	128	235
50	362	1130	503	148	262

Table 3: Average Mechanical Properties of Selected Ductile (Nodular) Iron

Grade*	Ultimate Tensile Strength S_{ut}, MPa	Ultimate Compressive Strength S_{uc}, MPa	Tensile Yield Strength S_{yt}, MPa	Brinell Hardness , H_B	Elongation (%) 50 mm
60-40-18	461	359	329	167	15.0
65-45-12	464	362	332	167	15.0
80-55-06	559	386	362	192	11.2
120-90-02	974	920	864	331	1.5

Table 4: Mechanical Properties of Selected Steels

AISI No.	Processing	Ultimate Tensile Strength S_{ut}, MPa	Tensile Yield Strength S_{yt}, MPa	Brinell Hardness, H_B	Elongation (%)
1015	HR	340	190	101	28
	CD	390	320	111	18
	Annealed	386	284	111	37
1020	HR	380	210	111	25
	CD	470	390	131	15
	Annealed	395	296	111	36
1040	HR	520	290	149	10
	CD	590	490	170	12
	Normalized	590	374	170	28
	Annealed	519	353	149	30
1045	HR	570	310	163	16
	CD	630	530	179	12
1050	HR	620	340	179	15
	CD	690	580	197	10
	Normalized	748	427	217	20
	Annealed	636	365	187	24
	QT (425 C)	1090	793	444	13
1060	HR	680	370	201	12
	Normalized	776	421	229	18
	Annealed	626	372	179	22
	QT (425 C)	1080	765	311	14
1095	HR	830	460	248	10
	Normalized	1010	500	293	9
	Annealed	658	380	192	13
	QT (425 C)	1210	772	363	12
1118	HR	521	317	149	32
	Normalized	478	319	143	34
	Annealed	450	285	131	35
3140	Normalized	892	600	262	20
	Annealed	**690**	**423**	**197**	**25**
4130	**Normalized**	**670**	**436**	**197**	**25**
	Annealed	**560**	**361**	**156**	**28**
	QT (425 C)	**1280**	**1190**	**380**	**13**

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Table 5: Guide to Selection of Plain Carbon Steels

Carbon (%)	Typical Uses
0.05 – 0.10	Stampings, rivets, wire, cold drawn parts
0.10 – 0.20	Structural shapes, machine parts, carburized parts
0.20 – 0.30	Gears, shafts, levers, cold-forged parts, welded tubing, carburized parts
0.30 – 0.40	Shafts, gears, connecting rods, crane hooks
0.40 – 0.50	Gears, shafts, screws, forgings
0.50 – 0.70	Drawn-spring wire, lock washers, locomotive tires
0.70 – 0.90	Plowshares, shovels, leaf springs, hand tools
0.90 – 1.20	Springs, knives, drills, taps, milling cutters
1.20 – 1.40	Files, knives, razors, saws, wire-drawing dies.

Table 6: Mechanical Properties of Selected Non-Ferrous Materials

Material	**Processing**	**Ultimate Tensile Strength S_{ut}, MPa**	**Tensile Yield Strength S_{yt}, MPa**
Aluminum Alloys	1100-0	83	31
	2024-T4	448	296
	7075-0	234	99
	7075-T6	593	538
Magnesium Alloys	HK31XA-0	176	131
	HK31XA-H24	250	214
Copper Alloys	90-10 Brass A	251	58
	80-20 Brass A	247	50
	70-30 Brass A	303	72

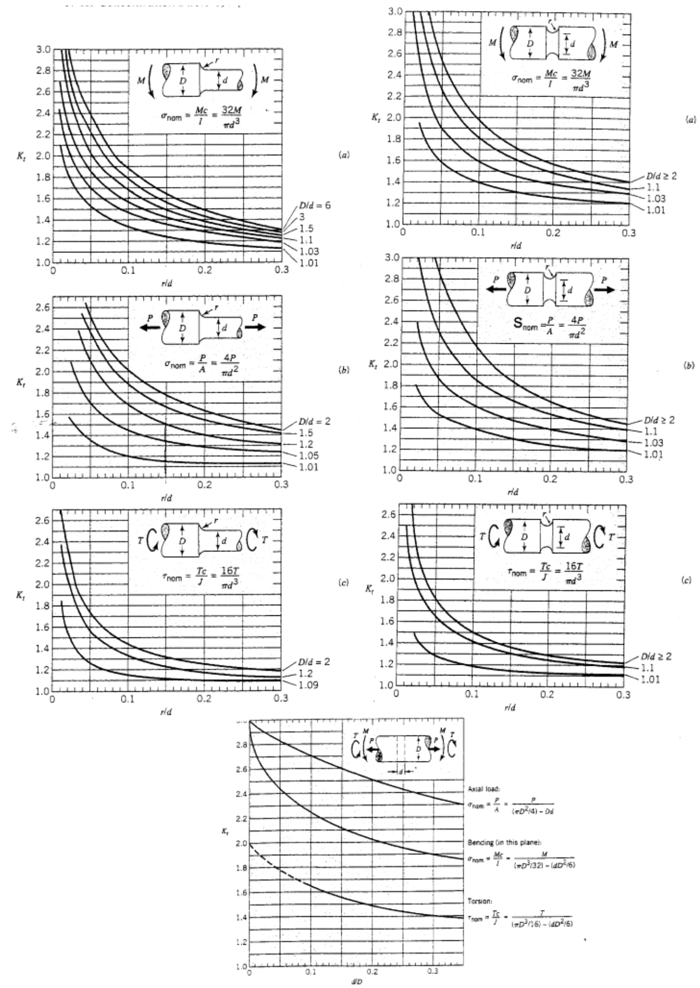
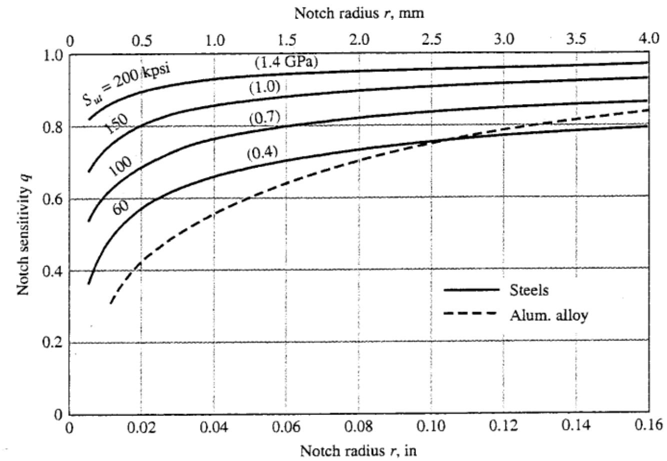
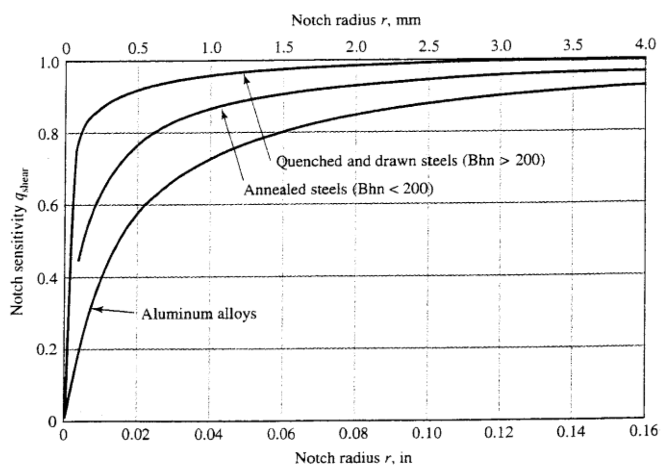


Figure 1: Stress Concentration Factors





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KEYS AND KEYWAYS

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Table 1: KEY SIZE VERSUS SHAFT DIAMETER

Nominal Shaft Diameter		*Nominal Key Size*		
			Height, H	
Over	*To (Incl.)*	*Width*, W	*Square*	*Rectangular*
5/16	7/16	3/32	3/32	
7/16	9/16	1/8	1/8	3/32
9/16	7/8	3/16	3/16	1/8
7/8	1 1/4	1/4	1/4	3/16
1 1/4	1 3/8	5/16	5/16	1/4
1 3/8	1 3/4	3/8	3/8	1/4
1 3/4	2 1/4	1/2	1/2	3/8
2 1/4	2 3/4	5/8	5/8	7/16
2 3/4	3 1/4	3/4	3/4	1/2
3 1/4	3 3/4	7/8	7/8	5/8
3 3/4	4 1/2	1	1	3/4
4 1/2	5 1/2	1 1/4	1 1/4	7/8
5 1/2	6 1/2	1 1/2	1 1/2	1
6 1/2	7 1/2	1 3/4	1 3/4	1 1/2
7 1/2	9	2	2	1 1/2
9	11	2 1/2	2 1/2	1 3/4
11	13	3	3	2
13	15	3 1/2	3 1/2	2 1/2
15	18	4		3
18	22	5		3 1/2
22	26	6		4
26	30	7		5

Note: Values in nonshaded areas preferred. Dimensions are in inches.

Source: ANSI Standard B17.1—1967, *Keys and Keyseats* (American Society of Mechanical Engineers, New York).

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Table 2: WOODRUFF KEY DIMENSIONS

Key Number	*Nominal Key Size,* W × B	*Actual Length,* F	*Height of Key,* C	*Shaft Keyseat Depth*	*Hub Keyseat Depth*
202	1/16 × 1/4	0.248	0.104	0.072 8	0.037 2
204	1/16 × 1/2	0.491	0.200	0.166 8	0.037 2
406	1/8 × 3/4	0.740	0.310	0.245 5	0.068 5
608	3/16 × 1	0.992	0.435	0.339 3	0.099 7
810	1/4 × 1 1/4	1.240	0.544	0.417 0	0.131 0
1210	3/8 × 1 1/4	1.240	0.544	0.354 5	0.193 5
1628	1/2 × 3 1/2	2.880	0.935	0.683 0	0.256 0
2428	3/4 × 3 1/2	2.880	0.935	0.558 0	0.381 0

Note: All dimensions given in inches.

Source: ANSI Standard B17.2—1967, *Woodruff Keys and Keyseats* (American Society of Mechanical Engineers, New York).

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BEARINGS

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TABLE 1: PERFORMANCE PARAMETERS FOR BEARING MATERIALS IN BOUNDARY LUBRICATION

Material	pV *psi-fpm*	pV *kW/m²*	*Wear Factor, K (10^{-10} in³·min/ ft·lb·h)*	*Coefficient of Friction*[a]
Copper-iron	75 000	2 625	—	—
Lead-bronze	60 000	2 100	—	—
Bronze	50 000	1 750	—	—
Aluminum	50 000	1 750	—	—
PPS filled with PTFE and glass	30 000	1 050	110	0.17
PTFE fabric	25 000	875	—	—
PTFE-bronze filled	21 000	735	5	0.13
PA filled with PTFE and glass	20 000	700	16	0.26
PTFE-glass filled	18 000	630	7	0.09
PTFE-PPS filled	15 000	525	1	0.13
Carbon-graphite	15 000	525	—	—
Nylon-filled with glass and PTFE	3 000	105	16	—

TABLE 2: BEARING MATERIALS PROPERTIES

	Material			
	Silicon Nitride	*52100 Steel*	*440C Stainless Steel*	*M50 Steel*
Room temperature hardness, HRC	78	62	60	64
Room temperature elastic modulus, 10^6 psi	45	30	29	28
Maximum operating temperature	1 200°C 2 200°F	180°C 360°F	260°C 500°F	320°C 600°F
Density, g/cc	3.2	7.8	7.8	7.6

TABLE 3 COMPARISON OF BEARING TYPES

Bearing Type	*Radial Load Capacity*	*Thrust Load Capacity*	*Misalignment Capability*
Single-row, deep-groove ball	Good	Fair	Fair
Double-row, deep-groove ball	Excellent	Good	Fair
Angular contact	Good	Excellent	Poor
Cylindrical roller	Excellent	Poor	Fair
Needle	Excellent	Poor	Poor
Spherical roller	Excellent	Fair/good	Excellent
Tapered roller	Excellent	Excellent	Poor

ABLE AA9: RADIAL AND THRUST FACTOR FOR SINGLE-ROW DEEP-GROOVE BALL BEARING

e	T/C_o	*Y*	*e*	T/C_o	*Y*
0.19	0.014	2.30	0.34	0.170	1.31
0.22	0.028	1.99	0.38	0.280	1.15
0.26	0.056	1.71	0.42	0.420	1.04
0.28	0.084	1.55	0.44	0.560	1.00
0.30	0.110	1.45			

Note: $X = 0.56$ for all values of Y.

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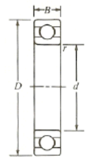
TABLE 4: BEARING SELECTION DATA FOR SINGLE-ROW, DEEP-GROOVE CONRAD-TYPE BALL BEARING

Table 15–2 Bearing Selection Data for Single-row, Deep-groove, Conrad-type Ball Bearings



Bearing Number	Nominal Bearing Dimensions d		D		B		r*	Preferred Shoulder Diameter Shaft	Housing	Bearing Weight	Basic Static Load Rating C_o	Basic Dynamic Load Rating C
	mm	in	mm	in	mm	in	in	in	in	lb	lb	lb
Series 6200												
6200	10	0.3937	30	1.1811	9	0.3543	0.024	0.500	0.984	0.07	520	885
6201	12	0.4724	32	1.2598	10	0.3937	0.024	0.578	1.063	0.08	675	1 180
6202	15	0.5906	35	1.3780	11	0.4331	0.024	0.703	1.181	0.10	790	1 320
6203	17	0.6693	40	1.5748	12	0.4724	0.024	0.787	1.380	0.14	1 010	1 660
6204	20	0.7874	47	1.8504	14	0.5512	0.039	0.969	1.614	0.23	1 400	2 210
6205	25	0.9843	52	2.0472	15	0.5906	0.039	1.172	1.811	0.29	1 610	2 430
6206	30	1.1811	62	2.4409	16	0.6299	0.039	1.406	2.205	0.44	2 320	3 350
6207	35	1.3780	72	2.8346	17	0.6693	0.039	1.614	2.559	0.64	3 150	4 450
6208	40	1.5748	80	3.1496	18	0.7087	0.039	1.811	2.874	0.82	3 650	5 050
6209	45	1.7717	85	3.3465	19	0.7480	0.039	2.008	3.071	0.89	4 150	5 650
6210	50	1.9685	90	3.5433	20	0.7874	0.039	2.205	3.268	1.02	4 650	6 050
6211	55	2.1654	100	3.9370	21	0.8268	0.059	2.441	3.602	1.36	5 850	7 500
6212	60	2.3622	110	4.3307	22	0.8661	0.059	2.717	3.996	1.73	7 250	9 050
6213	65	2.5591	120	4.7244	23	0.9055	0.059	2.913	4.390	2.18	8 000	9 900
6214	70	2.7559	125	4.9213	24	0.9449	0.059	3.110	4.587	2.31	8 800	10 800
6215	75	2.9528	130	5.1181	25	0.9843	0.059	3.307	4.783	2.64	9 700	11 400
6216	80	3.1496	140	5.5118	26	1.0236	0.079	3.504	5.118	3.09	10 500	12 600
6217	85	3.3465	150	5.9055	28	1.1024	0.079	3.740	5.512	3.97	12 300	14 600
6218	90	3.5433	160	6.2992	30	1.1811	0.079	3.937	5.906	4.74	14 200	16 600
6219	95	3.7402	170	6.6929	32	1.2598	0.079	4.213	6.220	5.73	16 300	18 800
6220	100	3.9370	180	7.0866	34	1.3386	0.079	4.409	6.614	6.94	18 600	21 100
6221	105	4.1339	190	7.4803	36	1.4173	0.079	4.606	7.008	8.15	20 900	23 000
6222	110	4.3307	200	7.8740	38	1.4961	0.079	4.803	7.402	9.59	23 400	24 900
6224	120	4.7244	215	8.4646	40	1.5748	0.079	5.197	7.992	11.4	26 200	26 900

Bearing Number	Nominal Bearing Dimensions d		D		B		r*	Preferred Shoulder Diameter Shaft	Housing	Bearing Weight	Basic Static Load Rating C_o	Basic Dynamic Load Rating C
	mm	in	mm	in	mm	in	in	in	in	lb	lb	lb
Series 6200												
6226	130	5.1181	230	9.0551	40	1.5748	0.098	5.669	8.504	12.7	29 100	28 700
6228	140	5.5118	250	9.8425	42	1.6535	0.098	6.063	9.291	19.6	29 300	28 700
6230	150	5.9055	270	10.6299	45	1.7717	0.098	6.457	10.079	25.3	32 500	30 000
6232	160	6.2992	290	11.4173	48	1.8898	0.098	6.850	10.886	32.0	35 500	32 000
6234	170	6.6929	310	12.2047	52	2.0472	0.118	7.362	11.535	38.5	43 000	36 500
6236	180	7.0866	320	12.5984	52	2.0472	0.118	7.758	11.929	41.0	46 500	39 000
6238	190	7.4803	340	13.3858	55	2.1654	0.118	8.150	12.717	50.5	54 500	44 000
6240	200	7.8740	360	14.1732	58	2.2835	0.118	8.543	13.504	61.5	60 000	46 500
Series 6300												
6300	10	0.3937	35	1.3780	11	0.4331	0.024	0.563	1.181	0.12	805	1 400
6301	12	0.4724	37	1.4567	12	0.4724	0.039	0.656	1.220	0.13	990	1 680
6302	15	0.5906	42	1.6535	13	0.5118	0.039	0.781	1.417	0.18	1 200	1 980
6303	17	0.6693	47	1.8504	14	0.5512	0.039	0.875	1.614	0.25	1 460	2 360
6304	20	0.7874	52	2.0472	15	0.5906	0.039	1.016	1.772	0.32	1 730	2 760
6305	25	0.9843	62	2.4409	17	0.6693	0.039	1.220	2.165	0.52	2 370	3 550
6306	30	1.1811	72	2.8346	19	0.7480	0.039	1.469	2.559	0.76	3 150	4 600
6307	35	1.3780	80	3.1496	21	0.8268	0.059	1.688	2.795	1.01	4 050	5 800
6308	40	1.5748	90	3.5433	23	0.9055	0.059	1.929	3.189	1.40	5 050	7 050
6309	45	1.7717	100	3.9370	25	0.9843	0.059	2.126	3.583	1.84	6 800	9 150
6310	50	1.9685	110	4.3307	27	1.0630	0.079	2.362	3.937	2.42	8 100	10 700
6311	55	2.1654	120	4.7244	29	1.1417	0.079	2.559	4.331	2.98	9 450	12 300
6312	60	2.3622	130	5.1181	31	1.2205	0.079	2.835	4.646	3.75	11 000	14 100
6313	65	2.5591	140	5.5118	33	1.2992	0.079	3.031	5.039	4.63	12 600	16 000
6314	70	2.7559	150	5.9055	35	1.3780	0.079	3.228	5.433	5.51	14 400	18 000
6315	75	2.9528	160	6.2992	37	1.4567	0.079	3.425	5.827	6.61	16 300	19 600

Bearing Number	Nominal Bearing Dimensions d		D		B		r*	Preferred Shoulder Diameter Shaft	Housing	Bearing Weight	Basic Static Load Rating C_o	Basic Dynamic Load Rating C
	mm	in	mm	in	mm	in	in	in	in	lb	lb	lb
Series 6300												
6316	80	3.1496	170	6.6929	39	1.5354	0.079	3.622	6.220	7.93	18 300	21 300
6317	85	3.3465	180	7.0866	41	1.6142	0.098	3.898	6.535	9.37	20 400	22 900
6318	90	3.5433	190	7.4803	43	1.6929	0.098	4.094	6.929	10.8	22 500	24 700
6319	95	3.7402	200	7.8740	45	1.7717	0.098	4.291	7.323	12.5	24 900	26 400
6320	100	3.9370	215	8.4646	47	1.8504	0.098	4.488	7.913	15.3	29 800	30 000
6321	105	4.1339	225	8.8583	49	1.9291	0.098	4.685	8.307	17.9	32 500	31 700
6322	110	4.3307	240	9.4488	50	1.9685	0.098	4.882	8.898	21.0	38 000	35 500
6324	120	4.7244	260	10.2362	55	2.1654	0.098	5.276	9.685	27.6	38 500	36 000
6326	130	5.1181	280	11.0236	58	2.2835	0.118	5.827	10.315	40.8	44 500	39 500
6328	140	5.5118	300	11.8110	62	2.4409	0.118	6.220	11.102	48.5	51 000	43 500
6330	150	5.9055	320	12.5984	65	2.5591	0.118	6.614	11.890	57.3	58 000	47 500
6332	160	6.2992	340	13.3858	68	2.6772	0.118	7.008	12.677	58	58 500	48 000
6334	170	6.6929	360	14.1732	72	2.8346	0.118	7.402	13.465	84	73 500	56 500
6336	180	7.0866	380	14.9606	75	2.9528	0.118	7.795	14.252	98	84 000	61 500
6338	190	7.4803	400	15.7480	78	3.0709	0.157	8.346	14.882	112	84 000	61 500
6340	200	7.8740	420	16.5354	80	3.1496	0.157	8.740	15.669	127	91 500	65 500

*Max fillet that corner radius will clear
Source: Hoover-NSK Bearing Company, Ann Arbor, Mich.

TABLE 5 RECOMMENDED DESIGN LIFE FOR BEARINGS

Application	*Design Life* L_{10}, *h*
Domestic appliances	1 000–2 000
Aircraft engines	1 000–4 000
Automotive	1 500–5 000
Agricultural equipment	3 000–6 000
Elevators, industrial fans, multipurpose gearing	8 000–15 000
Electric motors, industrial blowers, general industrial machines	20 000–30 000
Pumps and compressors	40 000–60 000
Critical equipment in continuous 24-h operation	100 000–200 000

Source: Eugene A. Avallone and Theodore Baumeister III, eds. *Marks' Standard Handbook for Mechanical Engineers*, 9th ed. New York: McGraw-Hill Book Company, 1986.

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TABLE 7: TAPERED ROLLER BEARING DATA

Bore	Outside Diameter	Width	a	Thrust Factor, Y	Basic Dynamic Load Rating, C
1.000 0	2.500 0	0.812 5	0.583	1.71	8 370
1.500 0	3.000 0	0.937 5	0.690	1.98	12 800
1.750 0	4.000 0	1.250 0	0.970	1.50	21 400
2.000 0	4.375 0	1.500 0	0.975	2.02	26 200
2.500 0	5.000 0	1.437 5	1.100	1.65	29 300
3.000 0	6.000 0	1.625 0	1.320	1.47	39 700
3.500 0	6.375 0	1.875 0	1.430	1.76	47 700

Note: Dimensions in inches. Load C in pounds for an L_{10} life of 1 million rev.

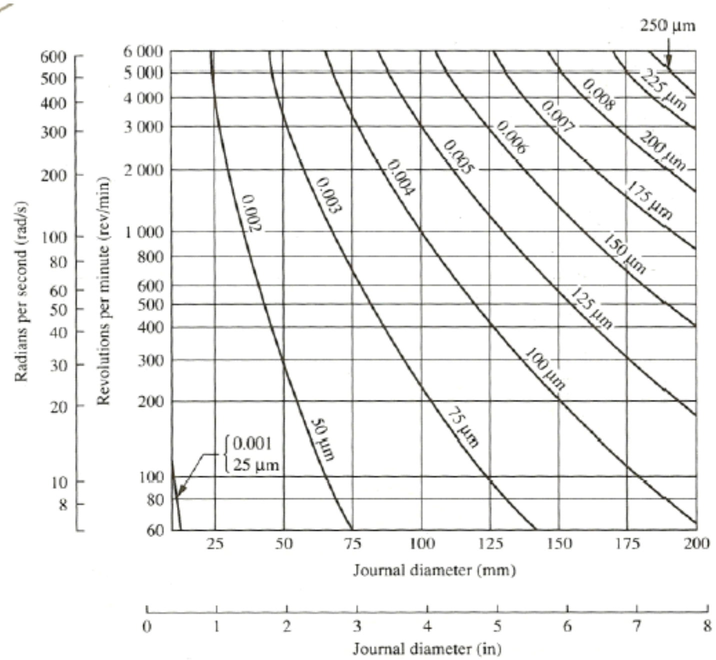

FIGURE 1: MINIMUM RECOMMENDED DIAMETRAL CLEARANCE FOR BEARINGS CONSIDERING JOURNAL DIAMETER AND ROTATIONAL SPEED

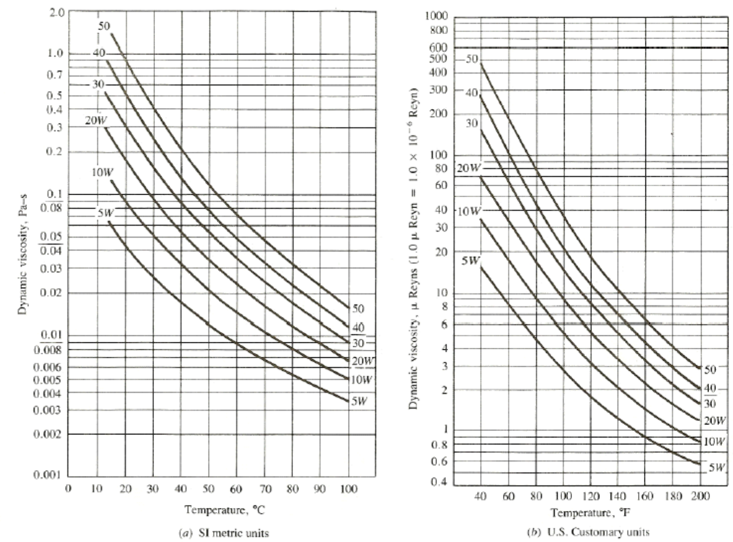

FIGURE 2: VISCOSITY VERSUS TEMPERATURE FOR SAE OILS

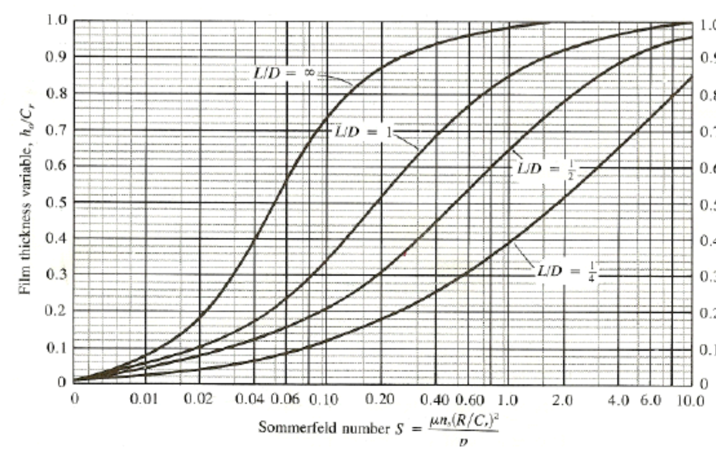

FIGURE 3: FILM THICKNESS VARIABLE, h_o/C_r " VERSUS SOMMERFELD NUMBER, S

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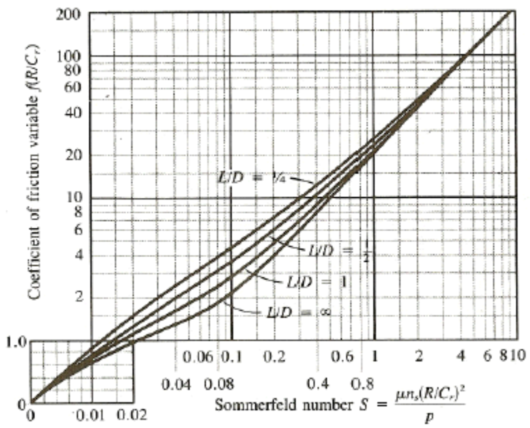

FIGURE 4: COEFFICIENT OF FRICTION VARIABLE, *F(R/C)*, VERSUS SOMMERFELD NUMBER, S

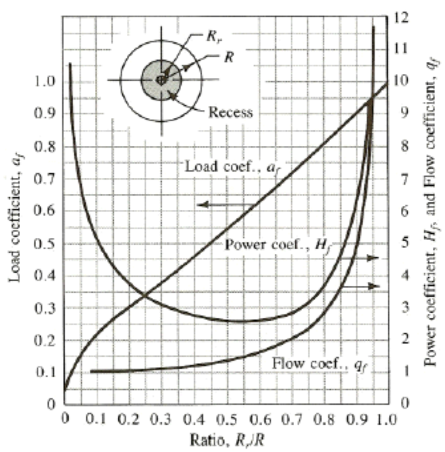

FIGURE 5: DIMENSIONLESS PERFORMANCE COEFFICIENTS FOR CIRCULAR PAD HYDROSTATIC BEARING

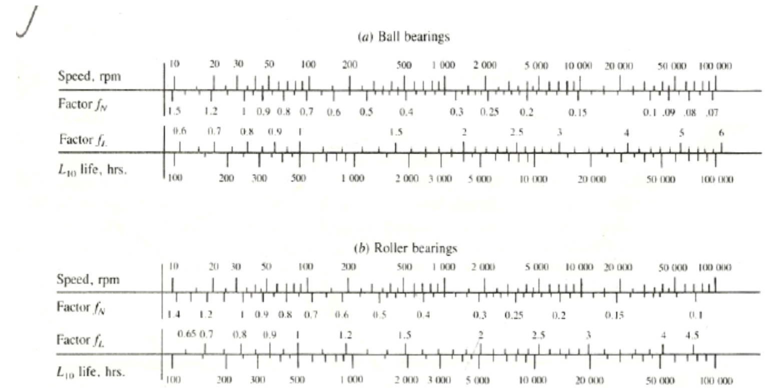

FIGURE 6: LIFE AND SPEED FACTORS FOR BALL AND ROLLER BEARINGS

APPENDIX B: DESIGN OF SPRINGS

APPENDIX-TAB AB1: TYPES OF BEARING

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Uses	Types of Springs
Push	Helical compression spring Belleville spring Torsion spring: force acting at the end of the torque arm Flat spring, such as a cantilever or leaf spring
Pull	Helical extension spring Torsion spring: force acting at the end of the torque arm Flat spring, such as a cantilever or leaf spring Drawbar spring (special case of the compression spring) Constant-force spring
Radial	Garter spring, elastomeric band, spring clamp
Torque	Torsion spring, power spring

APPENDIX-TAB AB2: WIRE GAGES AND DIAMETERS FOR SPRINGS

Gage No.	U.S. Steel Wire Gage (in)[a]	Music Wire Gage (in)[b]	Brown & Sharpe Gage (in)[c]	Preferred Metric Diamete (mm)[d]
7/0	0.490 0	—	—	13.0
6/0	0.461 5	0.004	0.580 0	12.0
5/0	0.430 5	0.005	0.516 5	11.0
4/0	0.393 8	0.006	0.460 0	10.0
3/0	0.362 5	0.007	0.409 6	9.0
2/0	0.331 0	0.008	0.364 8	8.5
0	0.306 5	0.009	0.324 9	8.0
1	0.283 0	0.010	0.289 3	7.0
2	0.262 5	0.011	0.257 6	6.5
3	0.243 7	0.012	0.229 4	6.0
4	0.225 3	0.013	0.204 3	5.5
5	0.207 0	0.014	0.181 9	5.0
6	0.192 0	0.016	0.162 0	4.8
7	0.177 0	0.018	0.144 3	4.5
8	0.162 0	0.020	0.128 5	4.0
9	0.148 3	0.022	0.114 4	3.8
10	0.135 0	0.024	0.101 9	3.5
11	0.120 5	0.026	0.090 7	3.0
12	0.105 5	0.029	0.080 8	2.8
13	0.091 5	0.031	0.072 0	2.5
14	0.080 0	0.033	0.064 1	2.0
15	0.072 0	0.035	0.057 1	1.8
16	0.062 5	0.037	0.050 8	1.6
17	0.054 0	0.039	0.045 3	1.4
18	0.047 5	0.041	0.040 3	1.2
19	0.041 0	0.043	0.035 9	1.0
20	0.034 8	0.045	0.032 0	0.90
21	0.031 7	0.047	0.028 5	0.80
22	0.028 6	0.049	0.025 3	0.70

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23	0.025 8	0.051	0.022 6	0.65
24	0.023 0	0.055	0.020 1	0.60 or 0.55
25	0.020 4	0.059	0.017 9	0.50 or 0.55
26	0.018 1	0.063	0.015 9	0.45
27	0.017 3	0.067	0.014 2	0.45
28	0.016 2	0.071	0.012 6	0.40
29	0.015 0	0.075	0.011 3	0.40
30	0.014 0	0.080	0.010 0	0.35
31	0.013 2	0.085	0.008 93	0.35
32	0.012 8	0.090	0.007 95	0.30 or 0.35
33	0.011 8	0.095	0.007 08	0.30
34	0.010 4	0.100	0.006 30	0.28
35	0.009 5	0.106	0.005 01	0.25
36	0.009 0	0.112	0.005 00	0.22
37	0.008 5	0.118	0.004 45	0.22
38	0.008 0	0.124	0.003 96	0.20
39	0.007 5	0.130	0.003 53	0.20
40	0.007 0	0.138	0.003 14	0.18

[a]Use the U.S. Steel Wire Gage for steel wire, except music wire. This gage has also been called the *Washburn and Moen Gage (W&M)*, the *American Steel Wire Co. Gage*, and the *Roebling Wire Gage*.

APPENDIX-TAB AB3 SPRING MATERIALS

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Material Type	ASTM No.	Relative Cost	Temperature Limits, °F
High-carbon steels:			
Hard drawn	A227	1.0	0 250
General-purpose steel with 0.60%–0.70% carbon; low cost			
Music wire	A228	2.6	
High-quality steel with 0.80%–0.95% carbon; very high strength; exce finish; hard drawn; good fatigue performance; used mostly in smaller 0.125 in			
Oil-tempered	A229	1.3	
General-purpose steel with 0.60%–0.70% carbon; used mostly in large 0.125 in; not good for shock or impact			
Alloy steels:			
Chromium-vanadium	A231	3.1	
Good strength, fatigue resistance, impact strength, high-temperature valve spring quality			
Chromium-silicon	A401	4.0	
Very high strength and good fatigue and shock resistance			
Stainless steels:			
Type 302	A313(302)	7.6	~0–550
Very good corrosion resistance and high-temperature performance; nearly nonmagnetic; cold drawn; types 304 and 316 also fall under this ASTM class and have improved workability but lower strength			
Type 17-7 PH	A313(631)	11.0	
Good high-temperature performance			
Copper alloys: All have good corrosion resistance and electrical condu			
Spring brass	B134	High	
Phosphor bronze	B159	8.0	
Beryllium copper	B197	27.0	
Nickel-base alloys: All are corrosion resistant, have good high- and lov properties, are nonmagnetic or nearly nonmagnetic (trade names of the International Nickel Company)			
Monel	—	—	−100–425
K-Monel	—	—	−100–450
Inconel	—	—	Up to 700
Inconel-X	—	44.0	Up to 850

APPENDIX-TAB AB4 SPRING WIRE MODULUS OF ELASTICITY IN SHEAR (G) AND TENSION (E)

Material And ASTM No.	Shear Modulus, G (psi)	Shear Modulus, G (GPa)	Tension Modulus, E (psi)	Tension Modulus, E (GPa)
Hard drawn steel: A227	11.5×10^6	79.3	28.6×10^6	197
Music wire: A228	11.85×10^6	81.7	29.0×10^6	200
Oil-tempered: A229	11.2×10^6	77.2	28.5×10^6	196
Chromium-vanadium: A231	11.2×10^6	77.2	28.5×10^6	196
Chromium-silicon: A401	11.2×10^6	77.2	29.5×10^6	203
Stainless steels: A313				
Types 302, 304, 316	10.0×10^6	69.0	28.0×10^6	193
Type 17-7 PH	10.5×10^6	72.4	29.5×10^6	203
Spring brass: B134	5.0×10^6	34.5	15.0×10^6	103
Phosphor bronze: B159	6.0×10^6	41.4	15.0×10^6	103
Beryllium copper: B197	7.0×10^6	48.3	17.0×10^6	117
Monel and K-Monel	9.5×10^6	65.5	26.0×10^6	179
Inconel and Inconel-X	10.5×10^6	72.4	31.0×10^6	214

Note: Data are average values. Slight variation with wire size and treatment may occur.

APPENDIX-TAB AB5 ALLOWABLE STRESSES FOR BOLTS

ASTM Grade	Allowable Shear Stress	Allowa Tensile
A307	10 Ksi (69 MPa)	20 Ksi (13
A325 and A449	17.5 Ksi (121 MPa)	44 Ksi (30
A490	22 Ksi (152 MPa)	54 Ksi (37

Base Metal ASTM Grade	*Electrode*	*Allowable Shear Stress*
Building Type Structures		
A36, A441	E60	13 600 psi
A36, A441	E70	15 800 psi
Bridge Type Structures		
A36	E60	12 400 psi
A441, A242	E70	14 700 psi

APPENDIX-TAB AB5 CONTINUES

Steel		
Electrode Type	*Typical Metals Joined (ASTM Grade)*	*Allowab Shear Str*
E60	A36, A500	18 Ksi (124
E70	A242, A441	21 Ksi (145
E80	A572 Grade 65	24 Ksi (165
E90	—	27 Ksi (186
E100	—	30 Ksi (207
E110	—	33 Ksi (228

Aluminum							
	Filler Alloy						
	1100		*4043*		*5356*		*555*
	Allowable Shear Stress						
Metal Joined	*Ksi*	*MPa*	*Ksi*	*MPa*	*Ksi*	*MPa*	*Ksi*
1100	3.2	22	4.8	33	—	—	—
3003	3.2	22	5.0	34	—	—	—
6061	—	—	5.0	34	7.0	48	8.5
6063	—	—	5.0	34	6.5	45	6.5

APPENDIX-TAB AB6 MINIMUM WELD SIZES FOR THICK PLATES

DR. P. Y. ANDOH, LECTURER
DEPT. OF MECH. ENG., KNUST, KUMAS

Plate Thickness (in)	*Minimum Leg Size for (in)*
≤½	3⁄16
>½–¾	¼
>¾–1½	5⁄16
>1½–2¼	⅜
>2¼–6	½
>6	⅝

APPENDIX-TAB AB7 PREFERRED ACME SCREW THREADS

Nominal Major Diameter (in)	*Threads per in* n	*Pitch,* p = 1/n *(in)*	*Minimum Minor Diameter (in)*	*Minimum Pitch Diameter (in)*	*Tensile Stress Area (in²)*
¼	16	0.062 5	0.161 8	0.204 3	0.026 32
5⁄16	14	0.071 4	0.214 0	0.261 4	0.044 38
⅜	12	0.083 3	0.263 2	0.316 1	0.065 89
7⁄16	12	0.083 3	0.325 3	0.378 3	0.097 20
½	10	0.100 0	0.359 4	0.430 6	0.122 5
⅝	8	0.125 0	0.457 0	0.540 8	0.195 5
¾	6	0.166 7	0.537 1	0.642 4	0.273 2
⅞	6	0.166 7	0.661 5	0.766 3	0.400 3
1	5	0.200 0	0.750 9	0.872 6	0.517 5
1⅛	5	0.200 0	0.875 3	0.996 7	0.688 1
1¼	5	0.200 0	0.999 8	1.121 0	0.883 1
1⅜	4	0.250 0	1.071 9	1.218 8	1.030
1½	4	0.250 0	1.196 5	1.342 9	1.266
1¾	4	0.250 0	1.445 6	1.591 6	1.811
2	4	0.250 0	1.694 8	1.840 2	2.454
2¼	3	0.333 3	1.857 2	2.045 0	2.982
2½	3	0.333 3	2.106 5	2.293 9	3.802
2¾	3	0.333 3	2.355 8	2.542 7	4.711
3	2	0.500 0	2.432 6	2.704 4	5.181
3½	2	0.500 0	2.931 4	3.202 6	7.388
4	2	0.500 0	3.430 2	3.700 8	9.985
4½	2	0.500 0	3.929 1	4.199 1	12.972
5	2	0.500 0	4.428 1	4.697 3	16.351

[a] Per inch of length of engagement.

APPENDIX-TAB AB8 SAE GRADES OF STEELS FOR FASTENER

DR. P. Y. ANDOH, LECTURER
DEPT. OF MECH. ENG., KNUST, KUMAS

Grade Number	Bolt Size (in)	Tensile Strength (Ksi)	Yield Strength (Ksi)	Proof Strength (Ksi)	Head Marking
1	¼–1½	60	36	33	None
2	¼–¾	74	57	55	None
	>¾–1½	60	36	33	
4	¼–1½	115	100	65	None
5	¼–1	120	92	85	
	>1–1½	105	81	74	
7	¼–1½	133	115	105	
8	¼–1½	150	130	120	

APPENDIX-TAB AB9 ASTM STANDARD BOLT STEELS

ASTM Grade	Bolt Size (in)	Tensile Strength (Ksi)	Yield Strength (Ksi)	Proof Strength (Ksi)	H Ma
A307	¼–4	60	(Not reported)		N
A325	½–1	120	92	85	
	>1–1½	105	81	74	
A354-BC	¼–2½	125	109	105	
A354-BD	¼–2½	150	130	120	
A449	¼–1	120	92	85	
	>1–1½	105	81	74	
	>1½–3	90	58	55	
A574	0.060–½	180	—	140	(Sock
	⅝–4	170	—	135	Caps

APPENDIX-TAB AB10 METRIC GRADES OF STEELS FOR BOLTS

Grade	Bolt Size	Tensile Strength (MPa)	Yield Strength (MPa)	Proof Strength (MPa)
4.6	M5–M36	400	240	225
4.8	M1.6–M16	420	340[a]	310
5.8	M5–M24	520	415[a]	380
8.8	M17–M36	830	660	600
9.8	M1.6–M16	900	720[a]	650
10.9	M6–M36	1 040	940	830
12.9	M1.6–M36	1 220	1 100	970

[a] Yield strengths approximate and not included in standard.

APPENDIX-TAB AB11 AMERICAN STANDARD THREAD DIMENSION, NUMBERED SIZES

		Coarse Threads: UNC		Fine Threads: UNF	
Size	Basic Major Diameter (in)	Threads per in	Tensile Stress Area (in^2)	Threads per in	Tensile Stress Area (in^2)
0	0.060 0	—	—	80	0.001
1	0.073 0	64	0.002 63	72	0.002
2	0.086 0	56	0.003 70	64	0.003
3	0.099 0	48	0.004 87	56	0.005
4	0.112 0	40	0.006 04	48	0.006
5	0.125 0	40	0.007 96	44	0.008
6	0.138 0	32	0.009 09	40	0.010
8	0.164 0	32	0.014 0	36	0.014
10	0.190 0	24	0.017 5	32	0.020
12	0.216 0	24	0.024 2	28	0.025

APPENDIX-TAB AB12 AMERICAN STANDARD THREAD DIMENSION, FRACTIONAL SIZES

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DEPT. OF MECH. ENG., KNUST, KUMAS

Size	Basic Major Diameter (in)	Coarse Threads: UNC — Threads per in	Coarse Threads: UNC — Tensile Stress Area (in^2)	Fine Thread — Threads per in
1/4	0.250 0	20	0.031 8	28
5/16	0.312 5	18	0.052 4	24
3/8	0.375 0	16	0.077 5	24
7/16	0.437 5	14	0.106 3	20
1/2	0.500 0	13	0.141 9	20
9/16	0.562 5	12	0.182	18
5/8	0.625 0	11	0.226	18
3/4	0.750 0	10	0.334	16
7/8	0.875 0	9	0.462	14
1	1.000	8	0.606	12
1 1/8	1.125	7	0.763	12
1 1/4	1.250	7	0.969	12
1 3/8	1.375	6	1.155	12
1 1/2	1.500	6	1.405	12
1 3/4	1.750	5	1.90	—
2	2.000	4 1/2	2.50	—

APPENDIX-TAB AB13 METRIC THREAD DIMENSIONS

Basic Major Diameter (mm)	Coarse Threads — Pitch (mm)	Coarse Threads — Tensile Stress Area (mm^2)	Fine Threads — Pitch (mm)	Fine Threads — Tensile Stress Area (mm^2)
1	0.25	0.460	—	—
1.6	0.35	1.27	0.20	1.57
2	0.4	2.07	0.25	2.45
2.5	0.45	3.39	0.35	3.70
3	0.5	5.03	0.35	5.61
4	0.7	8.78	0.5	9.79
5	0.8	14.2	0.5	16.1
6	1	20.1	0.75	22.0
8	1.25	36.6	1	39.2
10	1.5	58.0	1.25	61.2
12	1.75	84.3	1.25	92.1
16	2	157	1.5	167
20	2.5	245	1.5	272
24	3	353	2	384
30	3.5	561	2	621
36	4	817	3	865
42	4.5	1 121	—	—
48	5	1 473	—	—

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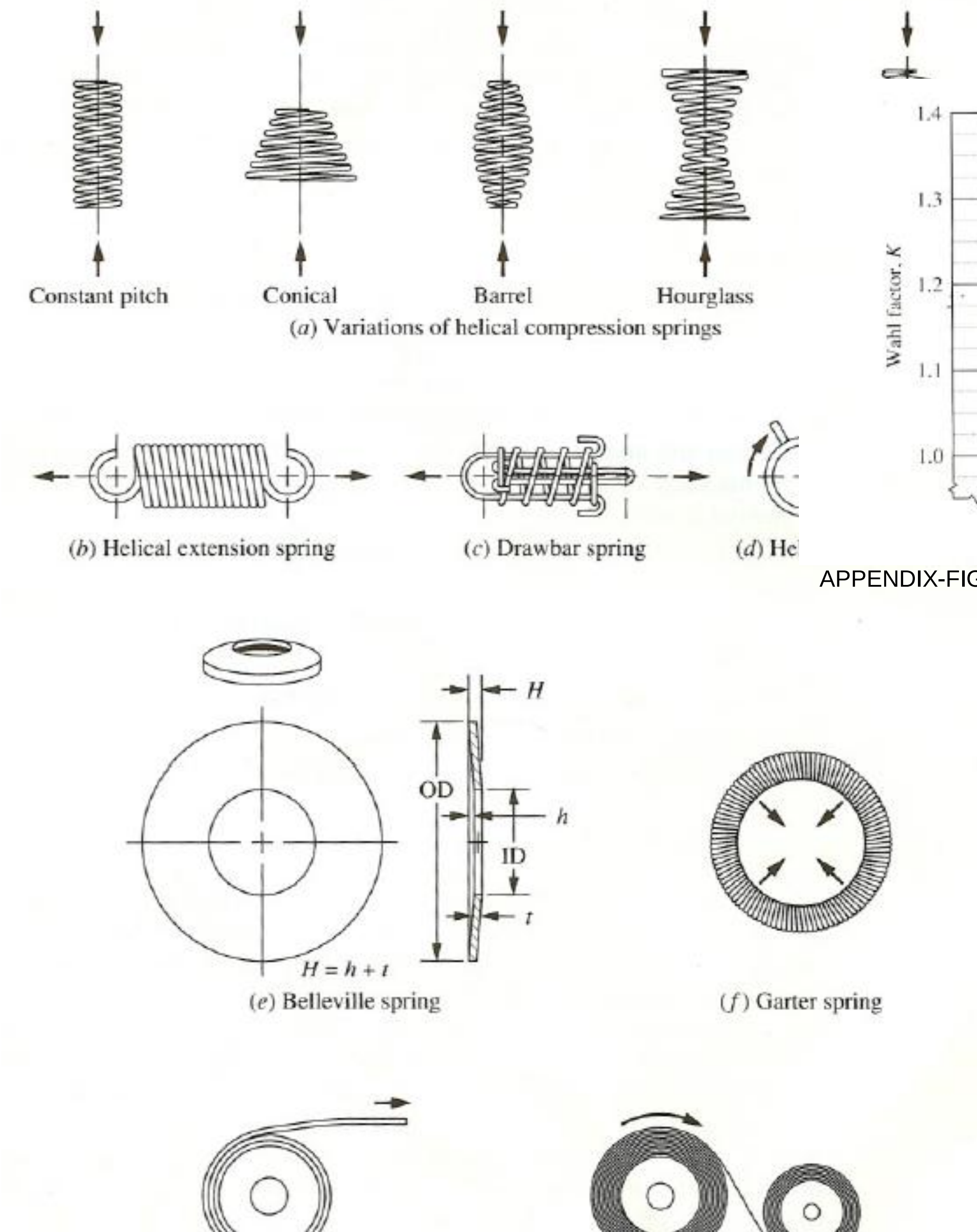
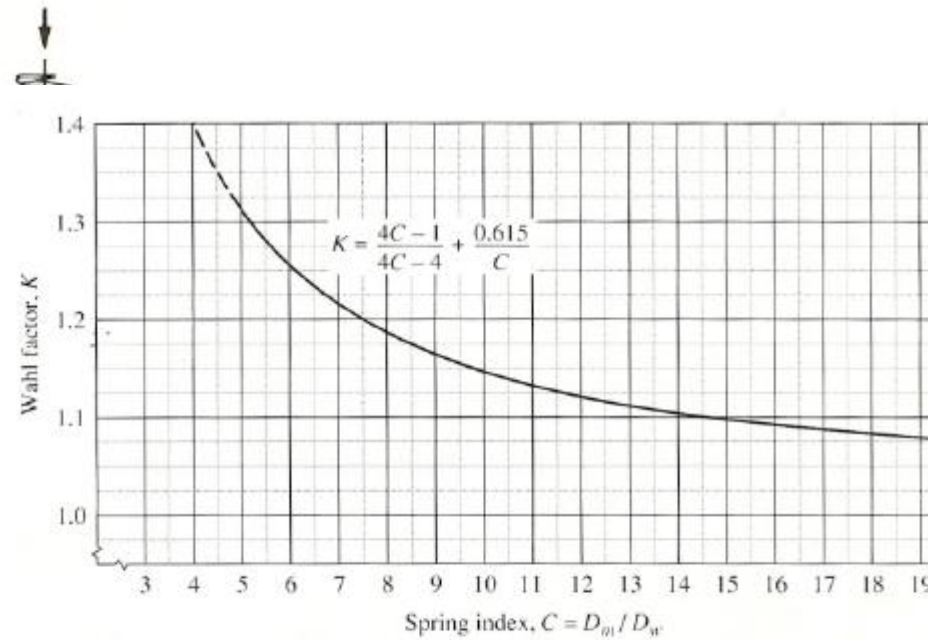
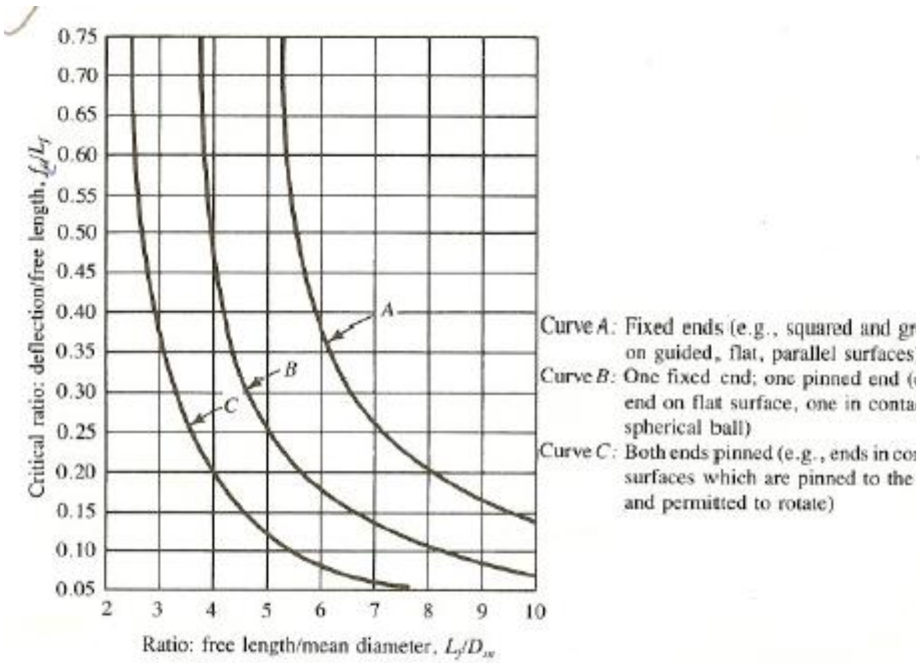
APPENDIX-FIG AB1: SEVERAL TYPES OF SPRINGS

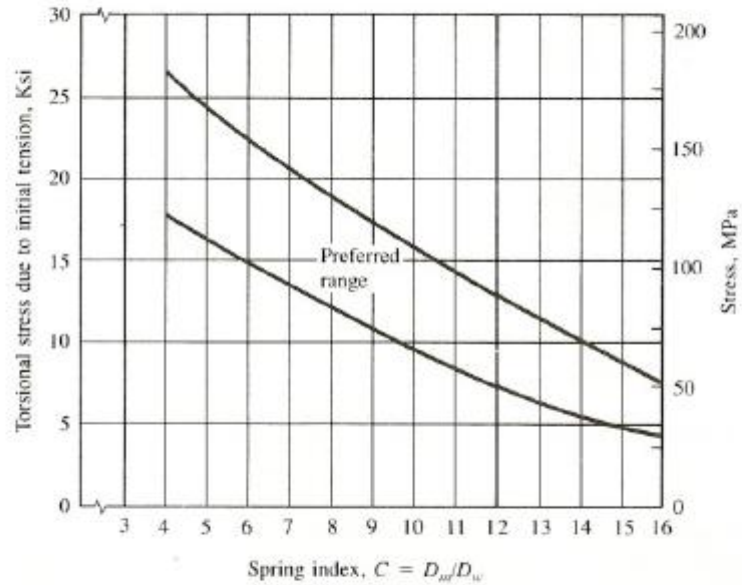




APPENDIX-FIG AB2: WAHL FACTOR VS. SPRING INDEX FOR ROUNDWIRE



APPENDIX-FIG AB3: SPRING BUCKLING CRITERIA.



APPENDIX-FIG AB4 RECOMMENDED TORSIONAL SHEAR STRESS IN AN EXTENSION SPRING DUE TO INITIAL TENSION (DATA FROM ASSOCIATED SPRING, BARNES GROUP, INC.)

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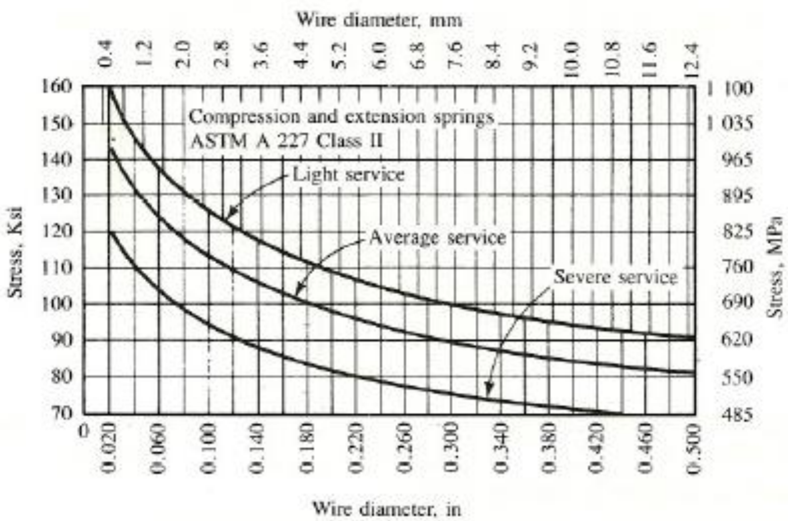
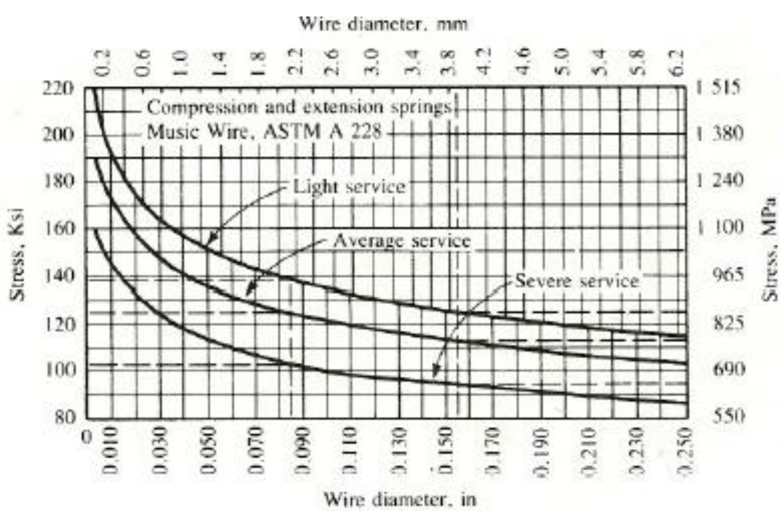
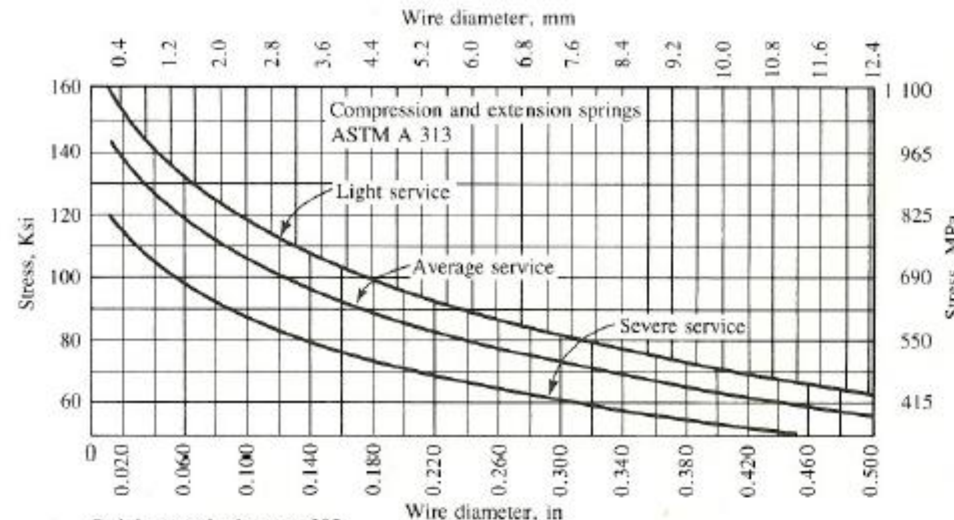


APPENDIX-FIG AB5 DESIGN STRESSES, ASTM A227 STEEL WIRE, HARD DRAWN
(REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 144, BY COURTESY OF MARCEL DEKKER, INC.)



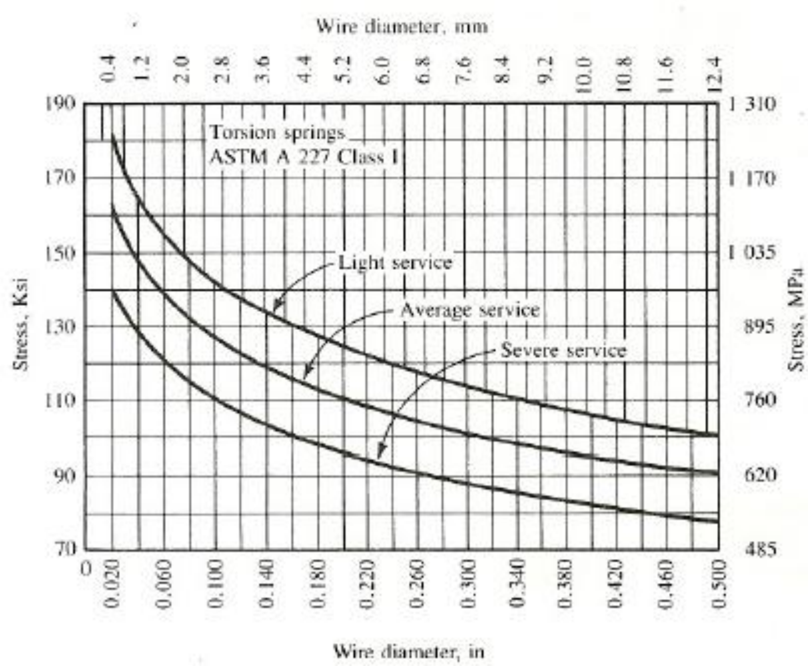
Similar design stresses for ASTM A 313, type 631 stainless steel wire, 17-7 PH

APPENDIX-FIG AB6 DESIGN STRESSES, ASTM A228 STEEL WIRE (MUSIC WIRE)
(REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 143, BY COURTESY OF MARCEL DEKKER. INC.)

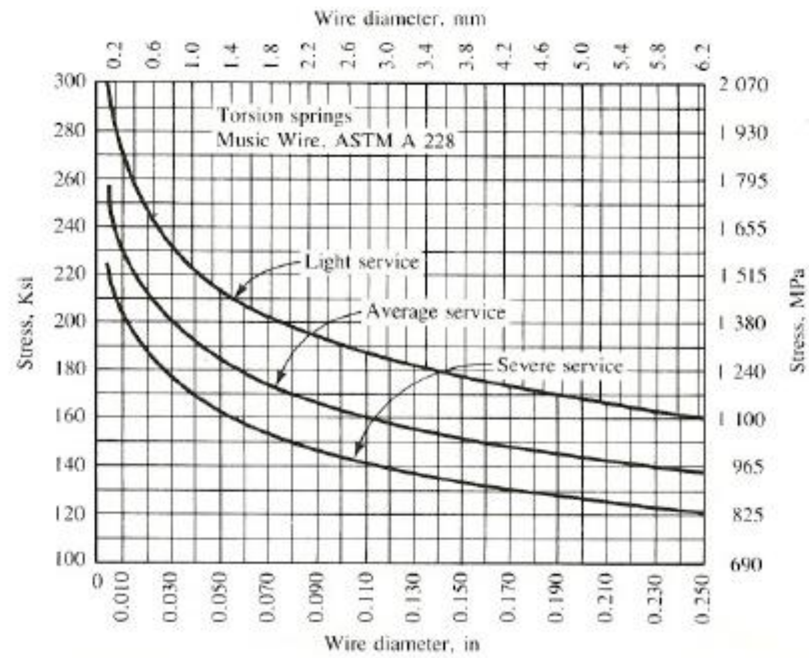


Stainless steel wire type 302
For type 304 multiply by 0.95
For type 316 multiply by 0.85

APPENDIX-FIG AB7 DESIGN STRESSES, ASTM A313 CORROSION-RESISTANT STAINLESS STEEL WIRE
(REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 15 BY COURTESY OF MARCEL DEKKER, INC.)



APPENDIX-FIG AB8 APPENDIX A-21-1 DESIGN STRESSES FOR TORSION SPRINGS ASTM A22? STEEL WIRE, HARD DRAWN (REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 144, BY COURTESY OF MARCEL DEKKER, INC.)



APPENDIX-FIG AB9 DESIGN SFRESSESFOR TORSION SPRINGSASTM A228 MUSIC WIN'
(REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 143, BY COURTESY OF MARCEL DEKKER, INC.)

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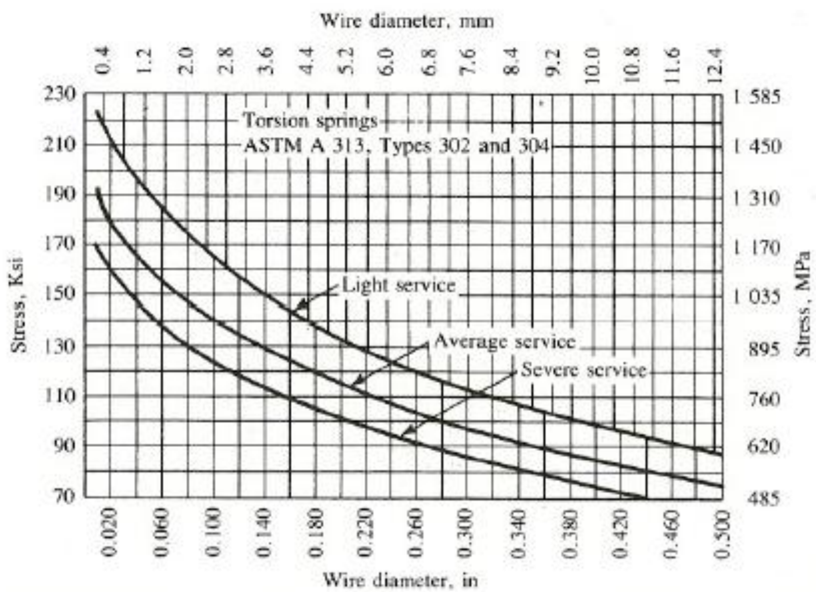
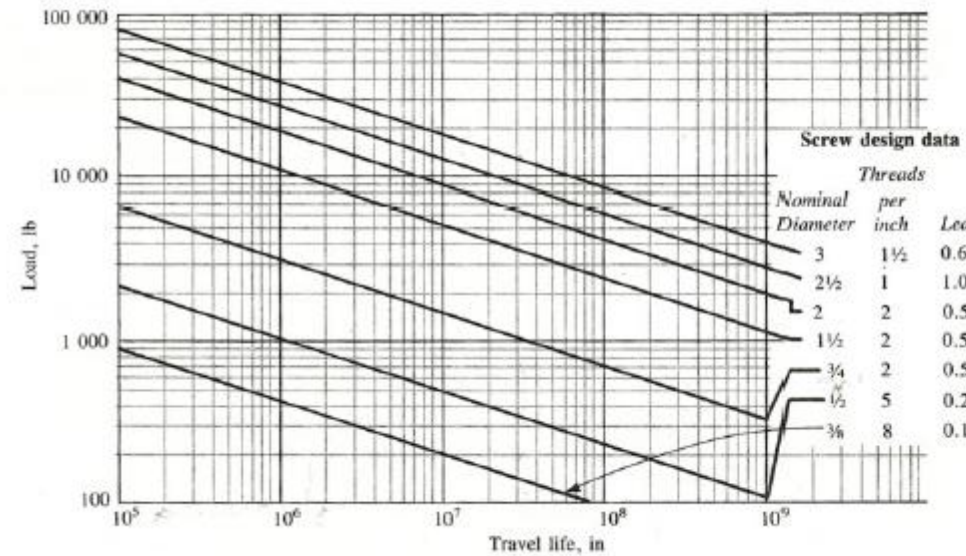


APPENDIX-FIG AB10 DESIGN STRESSES FOR TORSION SPRINGS ASTM A313 STAINLESS STEEL WIRE, TYPES 302 AND 304, CORROSION RESISTANT (REPRINTED FROM HAROLD CARLSON, *SPRING DESIGNER'S HANDBOOK,* P. 150, BY COURTESY OF MARCEL DEKKER, INC.)



APPENDIX-FIG AB12: BALL SCREW PERFORMANCE

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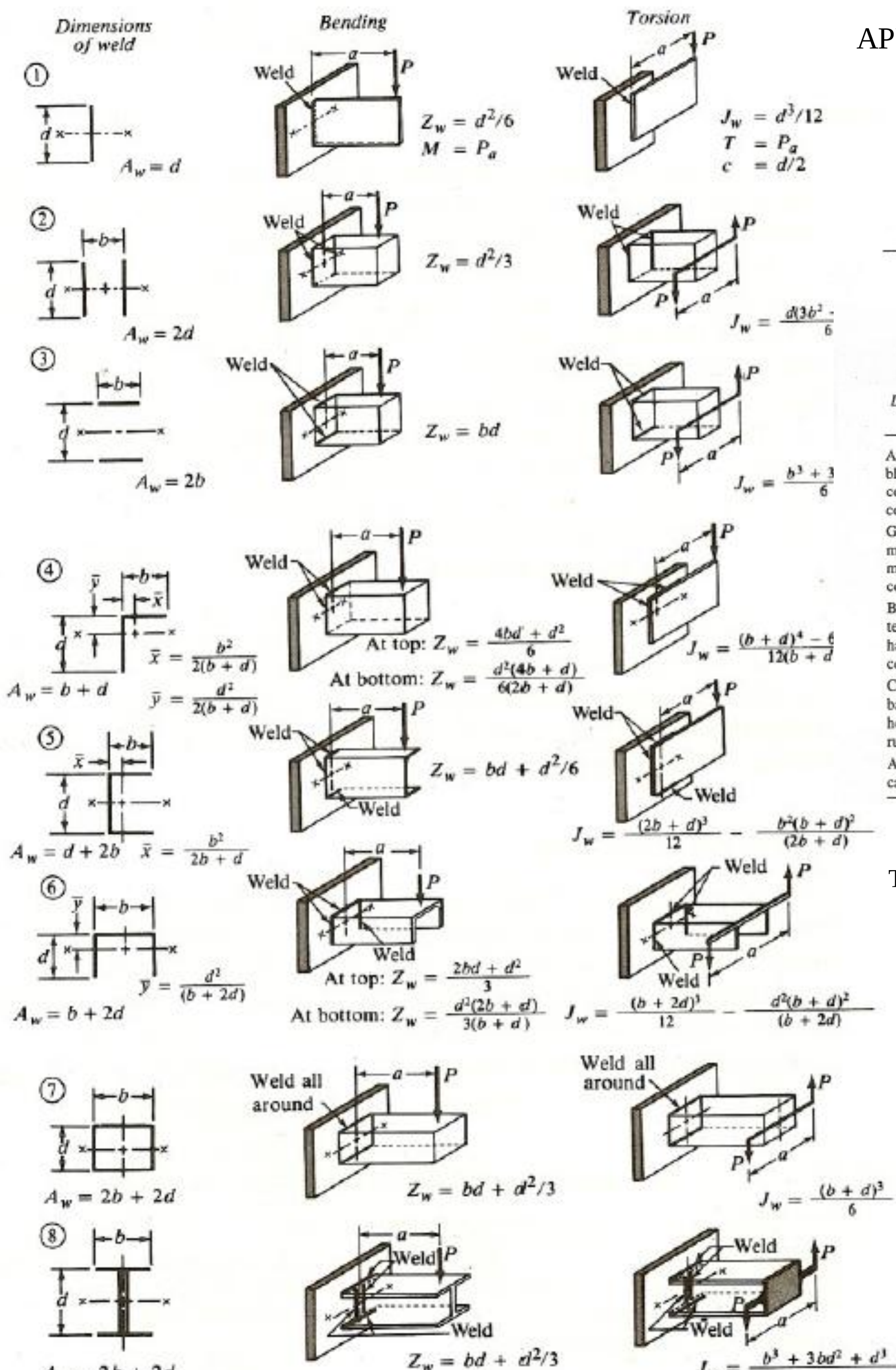

APPENDIX-FIG AB11: GEOMETRY FACTORS FOR WELD ANALYSIS

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Design of Flexible Drives

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Table 1: V-Belt Service Factor

	Driver Type					
	AC Motors: Normal Torque[a] DC Motors: Shunt-wound Engines: Multiple Cylinder			*AC Motors: High Torque[b] DC Motors: Series-wound, Compound-wound Engines: 4-cylinder or Less*		
Driven Machine Type	*<6 h per Day*	*6–15 h per Day*	*>15 h per Day*	*<6 h per Day*	*6–15 h per Day*	*>15 h per Day*
Agitators, blowers, fans, centrifugal pumps, conveyors, light	1.0	1.1	1.2	1.1	1.2	1.3
Generators, machine tools, mixers, conveyors, gravel	1.1	1.2	1.3	1.2	1.3	1.4
Bucket elevators, textile machines, hammer mills, conveyors, heavy	1.2	1.3	1.4	1.4	1.5	1.6
Crushers, ball mills, hoists, rubber extruders	1.3	1.4	1.5	1.5	1.6	1.8
Any machine that can choke	2.0	2.0	2.0	2.0	2.0	2.0

Table 2: Standard Belt Lengths for 3V, 5V, and *BV* Belts (in)

3V Only	*3V and 5V*	*3V, 5V, and 8V*	*5V and 8V*	*8V Only*
25	50	100	150	375
26.5	53	106	160	400
28	56	112	170	425
30	60	118	180	450
31.5	63	125	190	475
33.5	67	132	200	500
35.5	71	140	212	
37.5	75		224	
40	80		236	
42.5	85		250	
45	90		265	
47.5	95		280	
			300	
165			315	
			335	

Table 3 Roller Chain Sizes

Chain Number	*Pitch (in)*	*Average Tensile Strength (lb)*
25	¼	925
35	⅜	2 100
41	½	2 000
40	½	3 700
50	⅝	6 100
60	¾	8 500
80	1	14 500
100	1¼	24 000
120	1½	34 000
140	1¾	46 000
160	2	58 000
180	2¼	80 000
200	2½	95 000
240	3	130 000

Table 4 Service Factors for Chain Drives

Load Type	*Type of Driver*		
	Hydraulic Drive	*Electric Motor or Turbine*	*Internal Combustion Engine with Mechanical Drive*
Smooth (agitators, fans, light uniformly loaded conveyors)	1.0	1.0	1.2
Moderate shock (machine tools, cranes, heavy conveyors, food mixers and grinders)	1.2	1.3	1.4
Heavy shock (punch presses, hammer mills, reciprocating conveyors, rolling mill drive)	1.4	1.5	1.7

Table 5: Horsepower Ratings, Standard Single-strand Roller Chain, No. 40, 12.7-mm Pitch

No. Of Teeth Small Spkt.	*Revolutions Per Minute—Small Sprocket*																								
	10	*25*	*50*	*100*	*200*	*300*	*400*	*500*	*700*	*900*	*1 000*	*1 200*	*1 400*	*1 600*	*1 800*	*2 100*	*2 400*	*2 700*	*3 000*	*3 500*	*4 000*	*5 000*	*6 000*	*7 000*	*8 000*
9	0.04	0.10	0.19	0.35	0.65	0.93	1.21	1.48	2.00	2.51	2.75	3.25	3.73	4,12	3.45	2.74	2.24	1.88	1.60	1.27	1.04	0.75	0.57	0.45	0.37
10	0.05	0.11	0.21	0.39	0.73	1.04	1.35	1.65	2.24	2.81	3.09	3.64	4.18	4.71	4.04	3.21	2.63	2.20	1.88	1.49	1.22	0.87	0.66	0.53	0.43
11	0.05	0.12	0.23	0.43	0.80	1.16	1.50	1.83	2.48	3.11	3.42	4.03	4.63	5.22	4.66	3.70	3.03	2.54	2.17	1.72	1.41	1.01	0.77	0.61	0.50
12	0.06	0.14	0.25	0.47	0.88	1.27	1.65	2.01	2.73	3.42	3.76	4.43	5.09	5.74	5.31	4.22	3.45	2.89	2.47	1.96	1.60	1.15	0.87	0.69	0.57
13	0.06	0.15	0.28	0.52	0.96	1.39	1.80	2.20	2.97	3.73	4.10	4.83	5.55	6.26	5.99	4.76	3.89	3.26	2.79	2.21	1.81	1,29	0.98	0.78	0.64
14	0.07	0.16	0.30	0.56	1.04	1.50	1.95	2.38	3.22	4.04	4.44	5.23	6.01	6.78	6.70	5.31	4.35	3.65	3.11	2.47	2.02	1.45	1.10	0.87	0.71
15	0.07	0.17	0.32	0.60	1.12	1.62	2.10	2.56	3.47	4.35	4.78	5.64	6.47	7.30	7.43	5.89	4.82	4.04	3.45	2.74	2.24	1.60	1.22	0.97	0.79
16	0.08	0.19	0.35	0.65	1.20	1.74	2.25	2.75	3.72	4.66	5.13	6.04	6.94	7.83	8.18	6.49	5.31	4.45	3.80	3.02	2.47	1.77	1.34	1.07	0.87
17	0.08	0.20	0.37	0.69	1.29	1.85	2.40	2.93	3.97	4.98	5.48	6.45	7.41	8.36	8.96	7.11	5.82	4.88	4.17	3.31	2.71	1.94	1.47	1.17	0.96
18	0.09	0.21	0.39	0.73	1.37	1.97	2.55	3.12	4.22	5.30	5.82	6.86	7.88	8.89	9.76	7.75	6.34	5.31	4.54	3.60	2.95	2.11	1.60	1.27	0
19	0.09	0.22	0.42	0.78	1.45	2.09	2.71	3.31	4.48	5.62	6.17	7.27	8.36	9.42	10.5	8.40	6.88	5.76	4.92	3.91	3.20	2.29	1.74	1.38	0
20	0.10	0.24	0.44	0.82	1.53	2.21	2.86	3.50	4.73	5.94	6.53	7.69	8.83	9.96	11.1	9.07	7.43	6.22	5.31	4.22	3.45	2.47	1.88	1.49	0
21	0.11	0.25	0.46	0.87	1.62	2.33	3.02	3.69	4.99	6.26	6.88	8.11	9.31	10.5	11.7	9.76	7.99	6.70	5.72	4.54	3.71	2.66	2.02	1.60	0
22	0.11	0.26	0.49	0.91	1.70	2.45	3.17	3.88	5.25	6.58	7.23	8.52	9.79	11.0	12.3	10.5	8.57	7.18	6.13	4.87	3.98	2.85	2.17	1.72	0
23	0.12	0.27	0.51	0.96	1.78	2.57	3.33	4.07	5.51	6.90	7.59	8.94	10.3	11.6	12.9	11.2	9.16	7.68	6.55	5.20	4.26	3.05	2.32	1.84	0
24	0.13	0.29	0.54	1.00	1.87	2.69	3.48	4.26	5.76	7.23	7.95	9.36	10.8	12.1	13.5	11.9	9.76	8.18	6.99	5.54	4.54	3.25	2.47	1.96	0
25	0.13	0.30	0.56	1.05	1.95	2.81	3.64	4.45	6.02	7.55	8.30	9.78	11.2	12.7	14.1	12.7	10.4	8.70	7.43	5.89	4.82	3.45	2.63	0	
26	0.14	0.31	0.58	1.09	2.04	2.93	3.80	4.64	6.28	7.88	8.66	10.2	11.7	13.2	14.7	13.5	11.0	9.23	7.88	6.25	5.12	3.66	2.79	0	
28	0.15	0.34	0.63	1.18	2.20	3.18	4.11	5.03	6.81	8.54	9.39	11.1	12.7	14.3	15.9	15.0	12.3	10.3	8.80	6.99	5.72	4.09	3.11	0	
30	0.16	0.37	0.68	1.27	2.38	3.42	4.43	5.42	7.33	9.20	10.1	11.9	13.7	15.4	17.2	16.7	13.6	11.4	9.76	7.75	6.34	4.54	3.45	0	
32	0.17	0.39	0.73	1.36	2.55	3.67	4.75	5.81	7.86	9.86	10.8	12.8	14.7	16.5	18.4	18.4	15.0	12.6	10.8	8.64	6.99	5.00	0		
35	0.19	0.43	0.81	1.50	2.81	4.04	5.24	6.40	8.66	10.9	11.9	14.1	16.2	18.2	20.3	21.0	17.2	14.4	12.3	9.76	7.99	5.72	0		
40	0.22	0.50	0.93	1.74	3.24	4.67	6.05	7.39	10.0	12.5	13.8	16.3	18.7	21.1	23.4	25.7	21.0	17.6	15.0	11.9	9.76	6.99	0		
45	0.25	0.57	1.06	1.97	3.68	5.30	6.87	8.40	11.4	14.2	15.7	18.5	21.2	23.9	26.6	30.5	25.1	21.0	17.9	14.2	11.7	0			

Type I Type II Type III

Table 6: Horsepower Ratings, Standard Single-strand Roller Chain, No. 60, 19-mm Pitch

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No. Of Teeth Small Spkt.	Revolutions Per Minute—Small Sprocket																								
	10	25	50	100	150	200	300	400	500	600	700	800	900	1 000	1 100	1 200	1 400	1 600	1 800	2 000	2 500	3 000	3 500	4 000	4 500
9	0.15	0.33	0.62	1.16	1.67	2.16	3.12	4.04	4.94	5.82	6.68	7.54	8.38	9.21	9.99	8.77	6.96	5.70	4.77	4.08	2.92	2.22	1.76	1.44	1.21
10	0.16	0.37	0.70	1.30	1.87	2.43	3.49	4.53	5.53	6.52	7.49	8.44	9.39	10.3	11.2	10.3	8.15	6.67	5.59	4.77	3.42	2.60	2.06	1.69	1.41
11	0.18	0.41	0.77	1.44	2.07	2.69	3.87	5.02	6.13	7.23	8.30	9.36	10.4	11.4	12.5	11.9	9.41	7.70	6.45	5.51	3.94	3.00	2.38	1.95	1.63
12	0.20	0.45	0.85	1.58	2.28	2.95	4.25	5.51	6.74	7.94	9.12	10.3	11.4	12.6	13.7	13.5	10.7	8.77	7.35	6.28	4.49	3.42	2.71	2.22	1.86
13	0.22	0.50	0.92	1.73	2.49	3.22	4.64	6.01	7.34	8.65	9.94	11.2	12.5	13.7	14.9	15.2	12.1	9.89	8.29	7.08	5.06	3.85	3.06	2.50	0
14	0.24	0.54	1.00	1.87	2.69	3.49	5.02	6.51	7.96	9.37	10.8	12.1	13.5	14.8	16.2	17.0	13.5	11.1	9.26	7.91	5.66	4.31	3.42	2.80	0
15	0.25	0.58	1.08	2.01	2.90	3.76	5.41	7.01	8.57	10.1	11.6	13.1	14.5	16.0	17.4	18.8	15.0	12.3	10.3	8.77	6.28	4.77	3.79	3.10	0
16	0.27	0.62	1.16	2.16	3.11	4.03	5.80	7.52	9.19	10.8	12.4	14.0	15.6	17.1	18.7	20.2	16.5	13.5	11.3	9.66	6.91	5.26	4.17	3.42	0
17	0.29	0.66	1.24	2.31	3.32	4.30	6.20	8.03	9.81	11.6	13.3	15.0	16.7	18.3	19.9	21.6	18.1	14.8	12.4	10.6	7.57	5.76	4.57	3.74	0
18	0.31	0.70	1.31	2.45	3.53	4.58	6.59	8.54	10.4	12.3	14.1	15.9	17.7	19.5	21.2	22.9	19.7	16.1	13.5	11.5	8.25	6.28	4.98	4.08	0
19	0.33	0.75	1.39	2.60	3.74	4.85	6.99	9.05	11.1	13.0	15.0	16.9	18.8	20.6	22.5	24.3	21.4	17.5	14.6	12.5	8.95	6.81	5.40	4.42	0
20	0.35	0.79	1.47	2.75	3.96	5.13	7.38	9.57	11.7	13.8	15.8	17.9	19.8	21.8	23.8	25.7	23.1	18.9	15.8	13.5	9.66	7.35	5.83	0	
21	0.36	0.83	1.55	2.90	4.17	5.40	7.78	10.1	12.3	14.5	16.7	18.8	20.9	23.0	25.1	27.1	24.8	20.3	17.0	14.5	10.4	7.91	6.28	0	
22	0.38	0.87	1.63	3.05	4.39	5.68	8.19	10.6	13.0	15.3	17.5	19.8	22.0	24.2	26.4	28.5	26.6	21.8	18.2	15.6	11.1	8.48	6.73	0	
23	0.40	0.92	1.71	3.19	4.60	5.96	8.59	11.1	13.6	16.0	18.4	20.8	23.1	25.4	27.7	29.9	28.4	23.3	19.5	16.7	11.9	9.07	7.19	0	
24	0.42	0.96	1.79	3.35	4.82	6.24	8.99	11.6	14.2	16.8	19.3	21.7	24.2	26.6	29.0	31.3	30.3	24.8	20.8	17.8	12.7	9.66	7.67	0	
25	0.44	1.00	1.87	3.50	5.04	6.52	9.40	12.2	14.9	17.5	20.1	22.7	25.3	27.8	30.3	32.7	32.2	26.4	22.1	18.9	13.5	10.3	8.15	0	
26	0.46	1.05	1.95	3.65	5.25	6.81	9.80	12.7	15.5	18.3	21.0	23.7	26.4	29.0	31.6	34.1	34.2	28.0	23.4	20.0	14.3	10.9	8.65	0	
28	0.50	1.13	2.12	3.95	5.69	7.37	10.6	13.8	16.8	19.8	22.8	25.7	28.5	31.4	34.2	37.0	38.2	31.3	26.2	22.4	16.0	12.2	0		
30	0.54	1.22	2.28	4.26	6.13	7.94	11.4	14.8	18.1	21.4	24.5	27.7	30.8	33.8	36.8	39.8	42.4	34.7	29.1	24.8	17.8	13.5	0		
32	0.57	1.31	2.45	4.56	6.57	8.52	12.3	15.9	19.4	22.9	26.3	29.7	33.0	36.3	39.5	42.7	46.7	38.2	32.0	27.3	19.6	14.9	0		
35	0.63	1.44	2.69	5.03	7.24	9.38	13.5	17.5	21.4	25.2	29.0	32.7	36.3	39.9	43.5	47.1	53.4	43.7	36.6	31.3	22.4	17.0	0		
40	0.73	1.67	3.11	5.81	8.37	10.8	15.6	20.2	24.7	29.1	33.5	37.7	42.0	46.1	50.3	54.4	62.5	53.4	44.7	38.2	27.3	0			
45	0.83	1.89	3.53	6.60	9.50	12.3	17.7	23.0	28.1	33.1	38.0	42.0	47.7	52.4	57.1	61.7	70.9	63.7	53.4	45.6	32.6	0			
		Type I					Type II											Type III							

Source: Reprinted from Chains for Power Transmission and Material Handling, p. 140, by courtesy of Marcel Dekker, Inc.

Table 7: Horsepower Ratings, Standard Single-strand Roller Chain, No. 80, 25.4-mm Pitch

No. Of Teeth Small Spkt.	Revolutions Per Minute—Small Sprocket																							
	10	25	50	100	150	200	300	400	500	600	700	800	900	1 000	1 100	1 200	1 400	1 600	1 800	2 000	2 200	2 400	2 700	3 000	3 400
9	0.34	0.78	1.45	2.71	3.90	5.05	7.28	9.43	11.5	13.6	15.6	17.6	17.0	14.5	12.6	11.0	8.76	7.17	6.01	5.13	4.45	3.90	3.27	2.79	2.32
10	0.38	0.87	1.63	3.03	4.37	5.66	8.16	10.6	12.9	15.2	17.5	19.7	19.9	17.0	14.7	12.9	10.3	8.40	7.04	6.01	5.21	4.57	3.83	3.27	2.71
11	0.42	0.97	1.80	3.36	4.84	6.28	9.04	11.7	14.3	16.9	19.4	21.9	23.0	19.6	17.0	14.9	11.8	9.69	8.12	6.93	6.01	5.27	4.42	3.77	1.70
12	0.47	1.06	1.98	3.69	5.32	6.89	9.93	12.9	15.7	18.5	21.3	24.0	26.2	22.3	19.4	17.0	13.5	11.0	9.25	7.90	6.85	6.01	5.04	4.30	0
13	0.51	1.16	2.16	4.03	5.80	7.52	10.8	14.0	17.1	20.2	23.2	26.2	29.1	25.2	21.8	19.2	15.2	12.5	10.4	8.91	7.72	6.78	5.68	4.85	0
14	0.55	1.25	2.34	4.36	6.29	8.14	11.7	15.2	18.6	21.9	25.1	28.4	31.5	28.2	24.4	21.4	17.0	13.9	11.7	9.96	8.63	7.57	6.35	5.42	0
15	0.59	1.35	2.52	4.70	6.77	8.77	12.6	16.4	20.0	23.6	27.1	30.6	34.0	31.2	27.1	23.8	18.9	15.4	12.9	11.0	9.57	8.40	7.04	6.01	0
16	0.63	1.45	2.70	5.04	7.26	9.41	13.5	17.6	21.5	25.3	29.0	32.8	36.4	34.4	29.8	26.2	20.8	17.0	14.2	12.2	10.5	9.25	7.76	6.62	0
17	0.68	1.55	2.88	5.38	7.75	10.0	14.5	18.7	22.9	27.0	31.0	35.0	38.9	37.7	32.7	28.7	22.7	18.6	15.6	13.3	11.5	10.1	8.49	7.25	0
18	0.72	1.64	3.07	5.72	8.25	10.7	15.4	19.9	24.4	28.7	33.0	37.2	41.4	41.1	35.6	31.2	24.8	20.3	17.0	14.5	12.6	11.0	9.25	7.90	0
19	0.76	1.74	3.25	6.07	8.74	11.3	16.3	21.1	25.8	30.4	35.0	39.4	43.8	44.5	38.6	33.9	26.9	22.0	18.4	15.7	13.6	12.0	10.0	8.57	0
20	0.81	1.84	3.44	6.41	9.24	12.0	17.2	22.3	27.3	32.2	37.0	41.7	46.3	48.1	41.7	36.6	29.0	23.8	19.9	17.0	14.7	12.9	10.8	0	
21	0.85	1.94	3.62	6.76	9.74	12.6	18.2	23.5	28.8	33.9	39.0	43.9	48.9	51.7	44.8	39.4	31.2	25.6	21.4	18.3	15.9	13.9	11.7	0	
22	0.90	2.04	3.81	7.11	10.2	13.3	19.1	24.8	30.3	35.7	41.0	46.2	51.4	55.5	48.1	42.2	33.5	27.4	23.0	19.6	17.0	14.9	12.5	0	
23	0.94	2.14	4.00	7.46	10.7	13.9	20.1	26.0	31.8	37.4	43.0	48.5	53.9	59.3	51.4	45.1	35.8	29.3	24.6	21.0	18.2	15.9	13.4	0	
24	0.98	2.24	4.19	7.81	11.3	14.6	21.0	27.2	33.2	39.2	45.0	50.8	56.4	62.0	54.8	48.1	38.2	31.2	26.2	22.3	19.4	17.0	14.2	0	
25	1.03	2.34	4.37	8.16	11.8	15.2	21.9	28.4	34.7	40.9	47.0	53.0	59.0	64.8	58.2	51.1	40.6	33.2	27.8	23.8	20.6	18.1	15.1	0	
26	1.07	2.45	4.56	8.52	12.3	15.9	22.9	29.7	36.2	42.7	49.1	55.3	61.5	67.6	61.8	54.2	43.0	35.2	29.5	25.2	21.8	19.2	16.1	0	
28	1.16	2.65	4.94	9.23	13.3	17.2	24.8	32.1	39.3	46.3	53.2	59.9	66.7	73.3	69.0	60.6	48.1	39.4	33.0	28.2	24.4	21.4	0		
30	1.25	2.85	5.33	9.94	14.3	18.5	26.7	34.6	42.3	49.9	57.3	64.6	71.8	78.9	76.6	67.2	53.3	43.6	36.6	31.2	27.1	23.8	0		
32	1.34	3.06	5.71	10.7	15.3	19.9	28.6	37.1	45.4	53.5	61.4	69.2	77.0	84.6	84.3	74.0	58.7	48.1	40.3	34.4	29.8	26.2	0		
35	1.48	3.37	6.29	11.7	16.9	21.9	31.6	40.9	50.0	58.9	67.6	76.3	84.8	93.3	96.5	84.7	67.2	55.0	46.1	39.4	34.1	0			
40	1.71	3.89	7.27	13.6	19.5	25.3	36.4	47.2	57.7	68.0	78.1	88.1	98.0	108	117	103	82.1	67.2	56.3	48.1	20.0	0			
45	1.94	4.42	8.25	15.4	22.2	28.7	41.4	53.6	65.6	77.2	88.7	100	111	122	133	123	98.0	80.2	67.2	54.1	0				
		Type I				Type II											Type III								

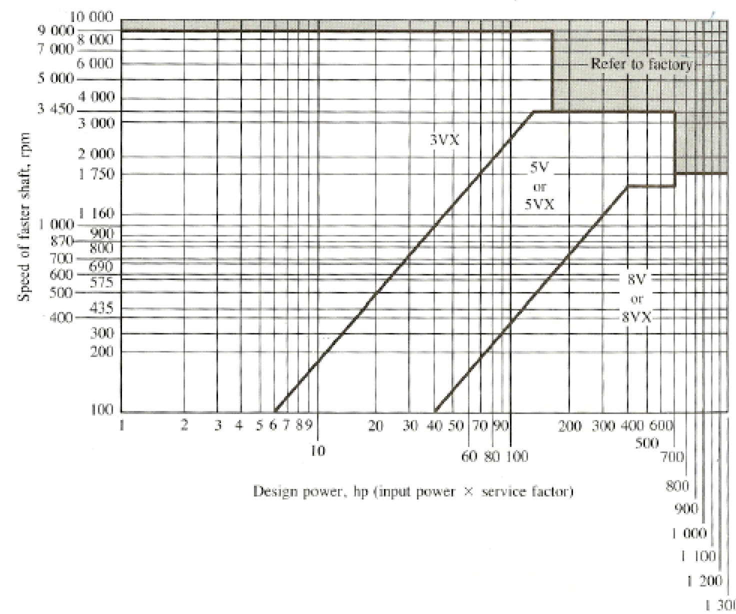

Figure 1: Selection Chart for Narrow-section Industrial V-belts

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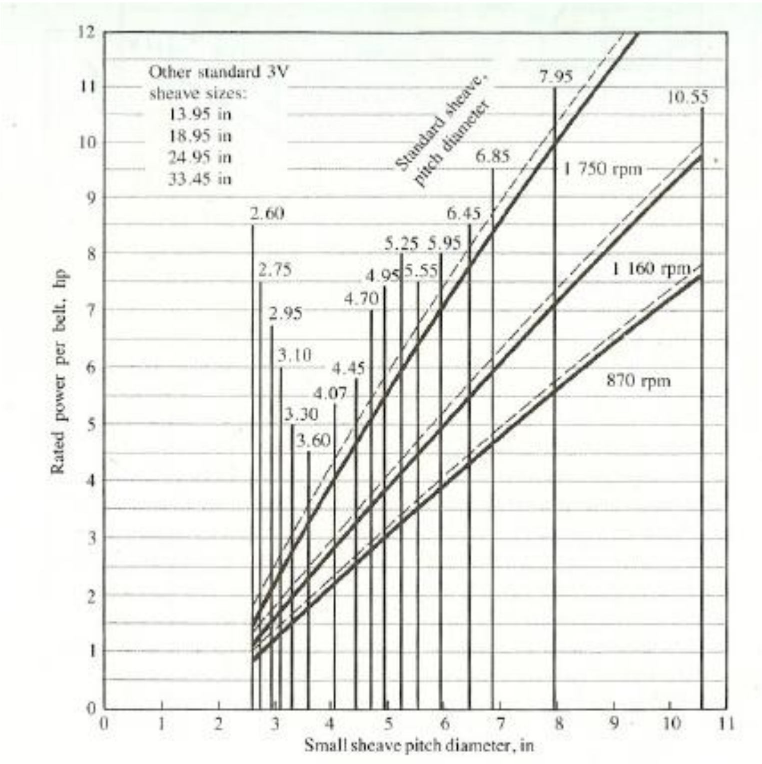

Figure 2: Power Rating: 3V Belts

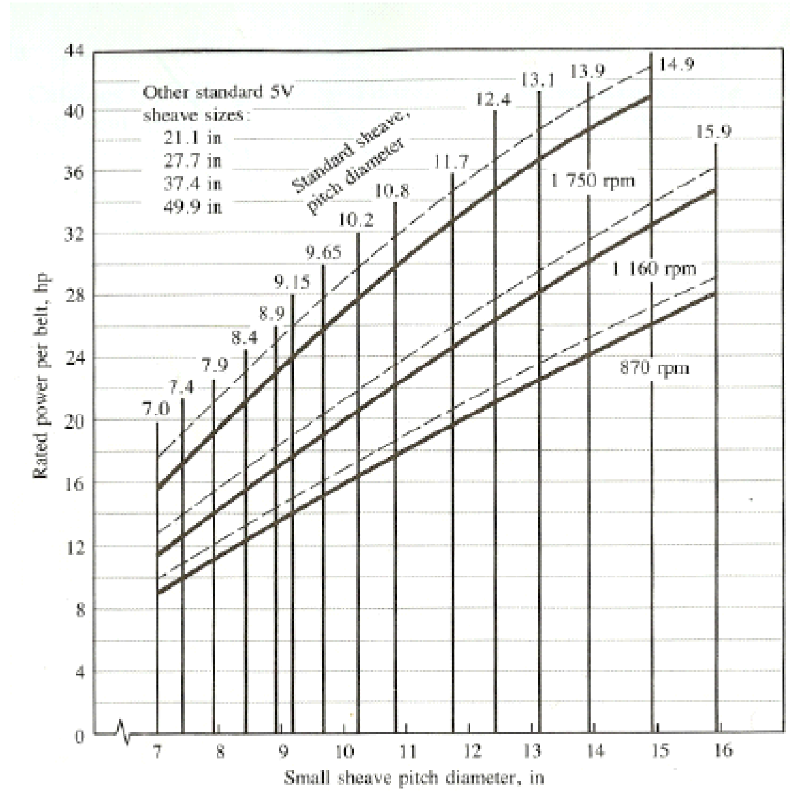

Figure 3: Power Rating: 5V Belts

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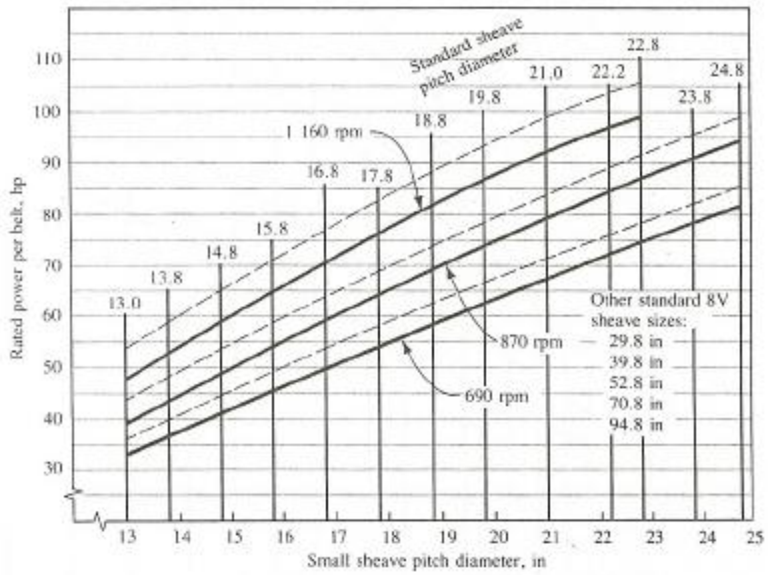

Figure 4: Power Rating: 8V Belts

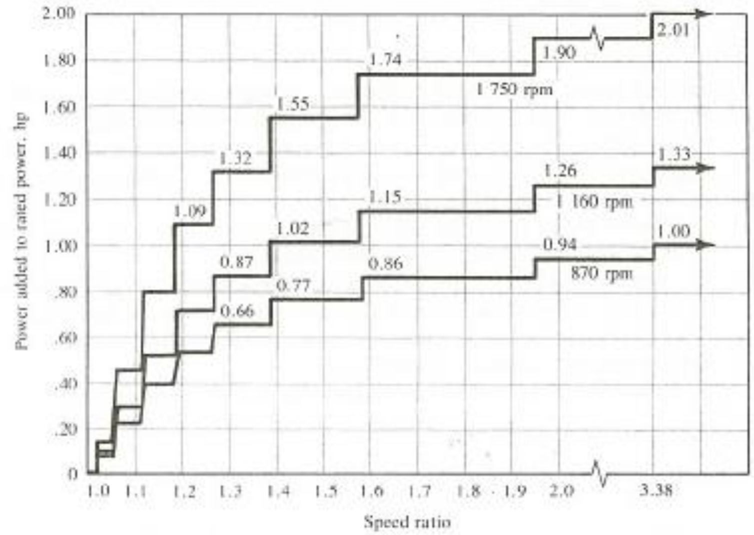

Figure 6: Power Added versus Speed Ratio: 5V Belts

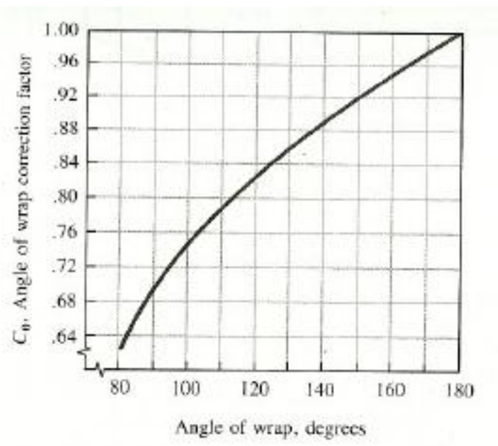

Figure 5: Angle of Wrap Correction Factor, C_o

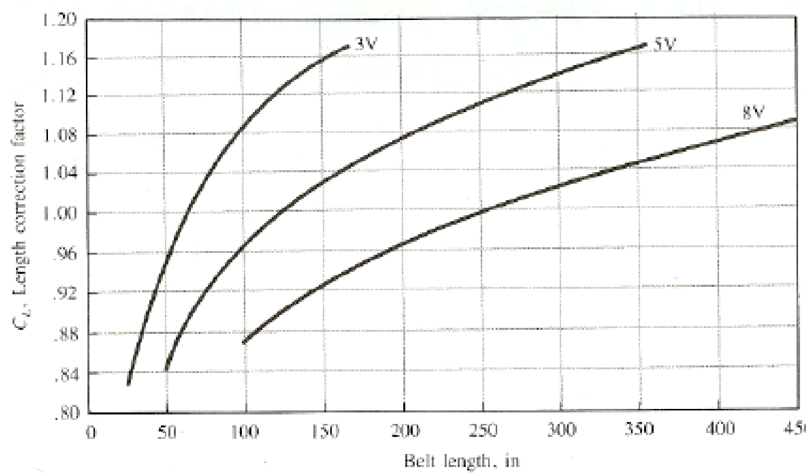

Figure 7: Belt Length Correction Factor, C_L

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****
Design of Gears
****

Table 1: Standard Circular Pitches (inches)

10.0	7.5	5.0
9.5	7.0	4.5
9.0	6.5	4.0
8.5	6.0	3.5
8.0	5.5	

Table 2: Standard Diametral Pitches (teeth/inch)

Coarse Pitch ($P_d < 20$)				*Fine Pitch* ($P_d \geq 20$)	
1	2	5	12	20	72
1.25	2.5	6	14	24	80
1.5	3	8	16	32	96
1.75	4	10	18	48	120
				64	

Table 3: Standard Modules

Module (mm)	*Equivalent* P_d	*Closest Standard* P_d *(Teeth/Inch)*
0.3	84.667	80
0.4	63.500	64
0.5	50.800	48
0.8	31.750	32
1	25.400	24
1.25	20.320	20
1.5	16.933	16
2	12.700	12
2.5	10.160	10
3	8.466	8
4	6.350	6
5	5.080	5
6	4.233	4
8	3.175	3
10	2.540	2.5
12	2.117	2
16	1.587	1.5
20	1.270	1.25
25	1.016	1

Table 4: Formulas for Gear-tooth Features for 20° Pressure Angle

Feature	*Symbol*	*Full-depth Involute System* *Coarse Pitch* ($P_d < 20$)	*Fine Pitch* ($P_d \geq 20$)	*Metric Module System*
Addendum	a	$1/P_d$	$1/P_d$	$1.00m$
Dedendum	b	$1.25/P_d$	$1.200/P_d + 0.002$	$1.25m$
Clearance	c	$0.25/P_d$	$0.200/P_d + 0.002$	$0.25m$

Table 5: Recommended Minimum Backlash for Coarse Pitch Gears

A. Diametral Pitch System (Backlash in Inches)

P_d	*Center Distance, C (in)* 2	4	8	16	32
18	0.005	0.006	—	—	—
12	0.006	0.007	0.009	—	—
8	0.007	0.008	0.010	0.014	—
5	—	0.010	0.012	0.016	—
3	—	0.014	0.016	0.020	0.028
2	—	—	0.021	0.025	0.033
1.25	—	—	—	0.034	0.042

B. Metric Module System (Backlash in Millimeters)

Module m	*Center Distance, C (mm)* 50	100	200	400	800
1.5	0.13	0.16	—	—	—
2	0.14	0.17	0.22	—	—
3	0.18	0.20	0.25	0.35	—
5	—	0.26	0.31	0.41	—
8	—	0.35	0.40	0.50	0.70
12	—	—	0.52	0.62	0.82
18	—	—	—	0.80	1.00

Source: Extracted from AGMA 2002-B88 Standard, *Tooth Thickness Specification and Measurement*, with permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Va. 22314.

Table 6: Number of Pinion Teeth to Ensure No Interference

For a Pinion Meshing with a Rack		*For a 20° Full-depth Pinion Meshing with a Gear*	
Tooth Form	*Minimum Number of Teeth*	*Number of Pinion Teeth*	*Maximum Number of Gear Teeth*
14½° Involute, Full-Depth	32	17	1309
20° Involute, Full-Depth	18	16	101
25° Involute, Full-Depth	12	15	45
		14	26
		13	16

Table 7: Allowable Stress Numbers for Through-hardened Steel Gear Materials

Hardness at Surface (HB)	*Allowable Bending Stress Number*				*Allowable Contact Stress Number*			
	Grade 1		*Grade 2*		*Grade 1*		*Grade 2*	
	(Ksi)	*(MPa)*	*(Ksi)*	*(MPa)*	*(Ksi)*	*(MPa)*	*(Ksi)*	*(MPa)*
Up to 180	25	170	33	230	85	590	95	660
240	31	210	41	280	105	720	115	790
300	36	250	47	325	120	830	135	930
360	40	280	52	360	145	1000	160	1100
400	42	290	56	390	155	1100	170	1200

Source: Extracted from AGMA Standard 2001-B88, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, with the permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Va. 22314.

Table 8: Approximate Allowable Tooth Bending Stress in Plastic Gears

Material	*Approximate Allowable Bending Stress, Ksi (MPa)*	
	Unfilled	*Glass-filled*
ABS	3 (21)	6 (41)
Acetal	5 (34)	7 (48)
Nylon	6 (41)	12 (83)
Polycarbonate	6 (41)	9 (62)
Polyester	3.5 (24)	8 (55)
Polyurethane	2.5 (17)	—

Source: *Plastics Gearing*. Manchester, Conn.: ABA/PGT Publishing, 1976.

Table 9: Allowable Stress Numbers for Case Hardened Steel Gear Materials

Hardness at Surface	*Allowable Bending Stress Number*				*Allowable Contact Stress Number*			
	Grade 1		*Grade 2*		*Grade 1*		*Grade 2*	
	(Ksi)	*(MPa)*	*(Ksi)*	*(MPa)*	*(Ksi)*	*(MPa)*	*(Ksi)*	*(MPa)*
Flame or Induction Hardened:								
50 HRC	45	310			170	1200	190	1300
54 HRC			55	380	175	1200	195	1300
Carburized and Case Hardened:								
55–64 HRC	55	380			180	1250		
58–64 HRC			65	450			225	1560
Nitrided AISI 4140:								
84.5 15N	34	230	45	310	155	1100	180	1250
Nitrided AISI 4340:								
83.5 15N	36	250	47	325	150	1050	175	1200
Nitrided Nitralloy 135M:[a]								
90.0 15N	38	260	48	330	170	1170	195	1350
Nitrided Nitralloy N:[a]								
90.0 15N	40	280	50	345	195	1340	205	1410

Table 10: Suggested Application Factor K_a

Power Source	*Driven Machine*			
	Uniform	*Light Shock*	*Moderate Shock*	*Heavy Shock*
Uniform	1.00	1.25	1.50	1.75
Light shock	1.20	1.40	1.75	2.25
Moderate shock	1.30	1.70	2.00	2.75

Table 11: Suggested Size Factor K_s

Diametral Pitch, P_d	*Metric Module, m*	*Size Factor K_s*
≥5	≤5	1.00
4	6	1.05
3	8	1.15
2	12	1.25
1.25	20	1.40

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Table 12 Allowable Stress Numbers for Iron and Bronze Gear Materials

Material Designation	Hardness at Surface (HB)	Allowable Bending Stress Number (Ksi)	Allowable Bending Stress Number (MPa)	Allowable Contact Stress Number (Ksi)	Allowable Contact Stress Number (MPa)
Gray Cast Iron—ASTM A48					
Class 20	—	5	35	50	340
Class 30	175	8.5	59	65	450
Class 40	200	13	90	75	520
Nodular (Ductile) Iron—ASTM A536					
60-14-18	140	22	150	77	530
80-55-06	180	22	150	77	530
100-70-03	230	27	180	92	630
120-90-02	270	31	210	103	710
Malleable Iron—ASTM A220					
45007	165	10	70	72	500
50005	180	13	90	78	540
53007	195	16	110	83	570
80002	240	21	145	94	650
Tin Bronze—UNS No. 90700—$s_{u\,min}$ = 40 Ksi (275 MPa)					
Bronze 2 (Former)		5.7	40	30	200
Aluminum Bronze—UNS No. 95400—$s_{u\,min}$ = 90 Ksi (620 MPa)					
ALBR 3 (Former)		23.6	160	65	450

Table 13: Basic Coefficient C_p

Pinion Material	Modulus of Elasticity E_P lb/in² (MPa)	Gear Material and Modulus of Elasticity E_G, lb/in² (MPa): Steel 30×10^6 (2×10^5)	Malleable Iron 25×10^6 (1.7×10^5)	Nodular Iron 24×10^6 (1.7×10^5)	Cast Iron 22×10^6 (1.5×10^5)	Aluminum Bronze 17.5×10^6 (1.2×10^5)	Tin Bronze 16×10^6 (1.1×10^5)
Steel	30×10^6 (2×10^5)	2 300 (191)	2 180 (181)	2 160 (179)	2 100 (174)	1 950 (162)	1 900 (158)
Mall. iron	25×10^6 (1.7×10^5)	2 180 (181)	2 090 (174)	2 070 (172)	2 020 (168)	1 900 (158)	1 850 (154)
Nod. iron	24×10^6 (1.7×10^5)	2 160 (179)	2 070 (172)	2 050 (170)	2 000 (166)	1 880 (156)	1 830 (152)
Cast iron	22×10^6 (1.5×10^5)	2 100 (174)	2 020 (168)	2 000 (166)	1 960 (163)	1 850 (154)	1 800 (149)
Al. bronze	17.5×10^6 (1.2×10^5)	1 950 (162)	1 900 (158)	1 880 (156)	1 850 (154)	1 750 (145)	1 700 (141)
Tin bronze	16×10^6 (1.1×10^5)	1 900 (158)	1 850 (154)	1 830 (152)	1 800 (149)	1 700 (141)	1 650 (137)

Note: Poisson's ratio = 0.30; Units for C_p are $(\text{lb/in}^2)^{0.5}$ or $(\text{MPa})^{0.5}$.

Source: Extracted from AGMA Standard 2001-B88, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, with the permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Va. 22314.

Table 14: Selected Values for Total Composite Tolerance

AGMA Quality Number	Diametral Pitch P_d	Number of Gear Teeth: 20	40	60	100	200
Q5	2	0.026 0	0.029 0	0.032 0	0.035 0	0.041 0
	8	0.012 0	0.013 0	0.014 0	0.015 0	0.017 0
	20	0.007 4	0.008 0	0.008 5	0.009 2	0.010 0
	32	0.006 0	0.006 4	0.006 8	0.007 3	0.008 0
Q8	2	0.009 4	0.011 0	0.012 0	0.013 0	0.015 0
	8	0.004 3	0.004 7	0.005 0	0.005 5	0.006 2
	20	0.002 7	0.002 9	0.003 1	0.003 4	0.003 7
	32	0.002 2	0.002 3	0.002 5	0.002 7	0.002 9
Q10	2	0.004 8	0.005 4	0.005 9	0.006 6	0.007 6
	8	0.002 2	0.002 4	0.002 6	0.002 8	0.003 2
	20	0.001 4	0.001 5	0.001 6	0.001 7	0.001 9
	32	0.001 1	0.001 2	0.001 3	0.001 4	0.001 5
Q12	2	0.002 5	0.002 8	0.003 0	0.003 4	0.003 9
	8	0.001 1	0.001 2	0.001 3	0.001 4	0.001 6
	20	0.000 71	0.000 77	0.000 81	0.000 87	0.000 97
	32	0.000 57	0.000 60	0.000 64	0.000 69	0.000 76
Q14	2	0.001 3	0.001 4	0.001 5	0.001 7	0.002 0
	8	0.000 57	0.000 62	0.000 67	0.000 73	0.000 82
	20	0.000 36	0.000 39	0.000 41	0.000 45	0.000 50
	32	0.000 29	0.000 31	0.000 33	0.000 35	0.000 39

Table 15: Recommended AGMA Quality Numbers

Application	Quality Number	Application	Quality Number
Cement mixer drum drive	3–5	Small power drill	7–9
Cement kiln	5–6	Clothes washing machine	8–10
Steel mill drives	5–6	Printing press	9–11
Grain harvester	5–7	Computing mechanism	10–11
Cranes	5–7	Automotive transmission	10–11
Punch press	5–7	Radar antenna drive	10–12
Mining conveyor	5–7	Marine propulsion drive	10–12
Paper-box-making machine	6–8	Aircraft engine drive	10–13
Gas meter mechanism	7–9	Gyroscope	12–14

Machine Tool Drives and Drives for Other High-Quality Mechanical Systems

Pitch Line Speed (fpm)	Quality Number	Pitch Line Speed (m/s)
0–800	6–8	0–4
800–2 000	8–10	4–11
2 000–4 000	10–12	11–22
Over 4 000	12–14	Over 22

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Table 16 Geometry Factors for Pitting Resistance, *I*, for Helical Gears with 20° Normal Pressure Angle and Standard Addendum

Gear Teeth	Pinion Teeth (helix angle ψ = 15.0°)				
	17	21	26	35	55
17	0.124				
21	0.139	0.128			
26	0.154	0.143	0.132		
35	0.175	0.165	0.154	0.137	
55	0.204	0.196	0.187	0.171	0.143
135	0.244	0.241	0.237	0.229	0.209

Gear Teeth	Pinion Teeth (helix angle ψ = 25.0°)					
	14	17	21	26	35	55
14	0.123					
17	0.137	0.126				
21	0.152	0.142	0.130			
26	0.167	0.157	0.146	0.134		
35	0.187	0.178	0.168	0.156	0.138	
55	0.213	0.207	0.199	0.189	0.173	0.144
135	0.248	0.247	0.244	0.239	0.230	0.210

Table 17 Load Distribution Factors for Bevel Gears, K_m

Type of Gearing	Both Gears Straddle-mounted	One Gear Straddle-mounted	Neither Gear Straddle-mounted
General commercial quality	1.44	1.58	1.80
High-quality commercial gearing	1.20	1.32	1.50

Table 18 Approximate Lewis Form Factor for Worm Gear Teeth

ϕ_n	y
14½°	0.100
20°	0.125
25°	0.150
30°	0.175

Table 19: Geometry Factor for Pitting-Resistance, *I*, for Helical 25° Normal Pressure Angle and Standard Addendum

Gear Teeth	Pinion Teeth (helix angle ψ = 15.0°)					
	14	17	21	26	35	55
14	0.130					
17	0.144	0.133				
21	0.160	0.149	0.137			
26	0.175	0.165	0.153	0.140		
35	0.195	0.186	0.175	0.163	0.143	
55	0.222	0.215	0.206	0.195	0.178	0.148
135	0.257	0.255	0.251	0.246	0.236	0.214

Gear Teeth	Pinion Teeth (helix angle ψ = 25.0°)						
	12	14	17	21	26	35	55
12	0.129						
14	0.141	0.132					
17	0.155	0.146	0.135				
21	0.170	0.162	0.151	0.138			
26	0.185	0.177	0.166	0.154	0.141		
35	0.203	0.197	0.188	0.176	0.163	0.144	
55	0.227	0.223	0.216	0.207	0.196	0.178	0.148
135	0.259	0.258	0.255	0.251	0.246	0.235	0.213

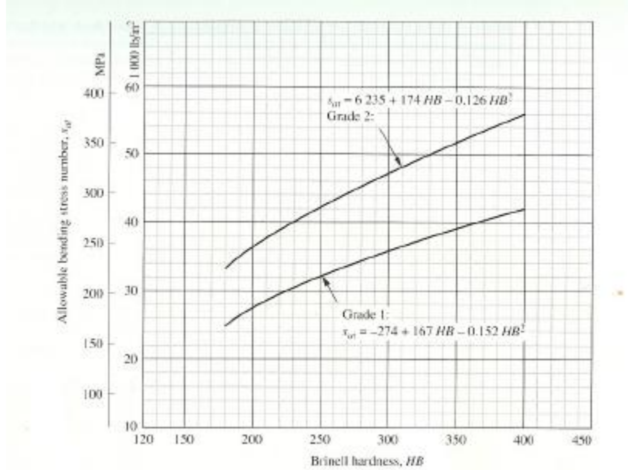

Figure 1: Allowable Bending Stress Number for Steel Gears

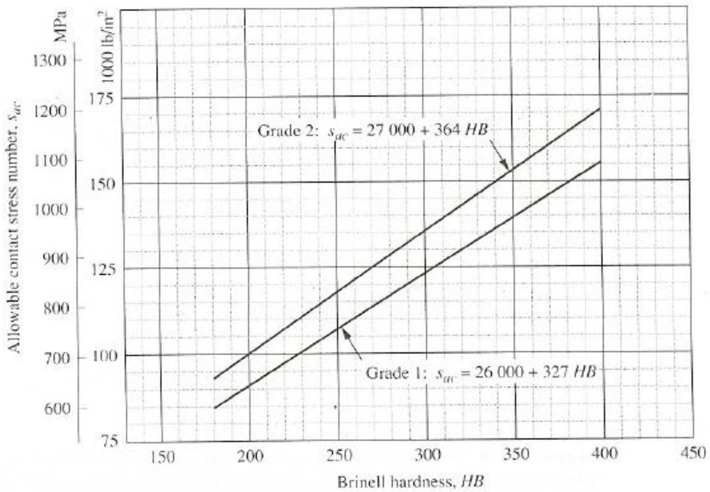

Figure 2: Allowable Contact Stress Number for Steel Gears,

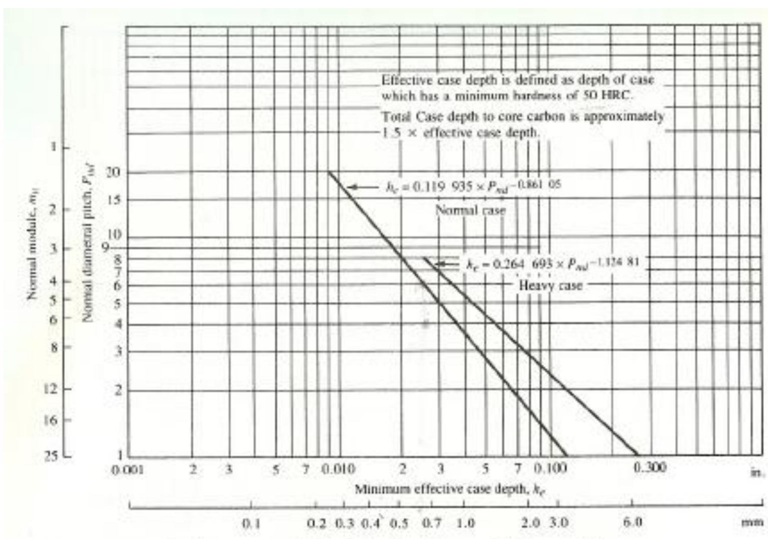

Figure 3: Effective Case Depth for Carburized Gears,

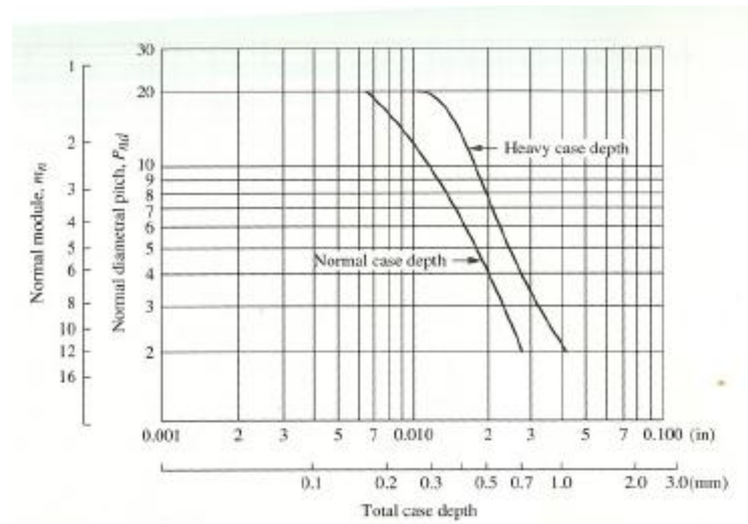

Figure 4: Recommended Case Depth for Nitrided Gears,

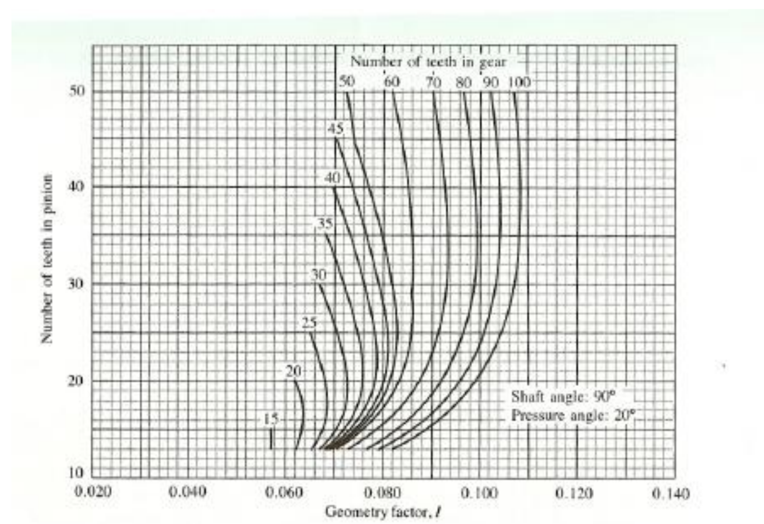

Figure 5 Geometry Factors for Straight and Bevel Gears

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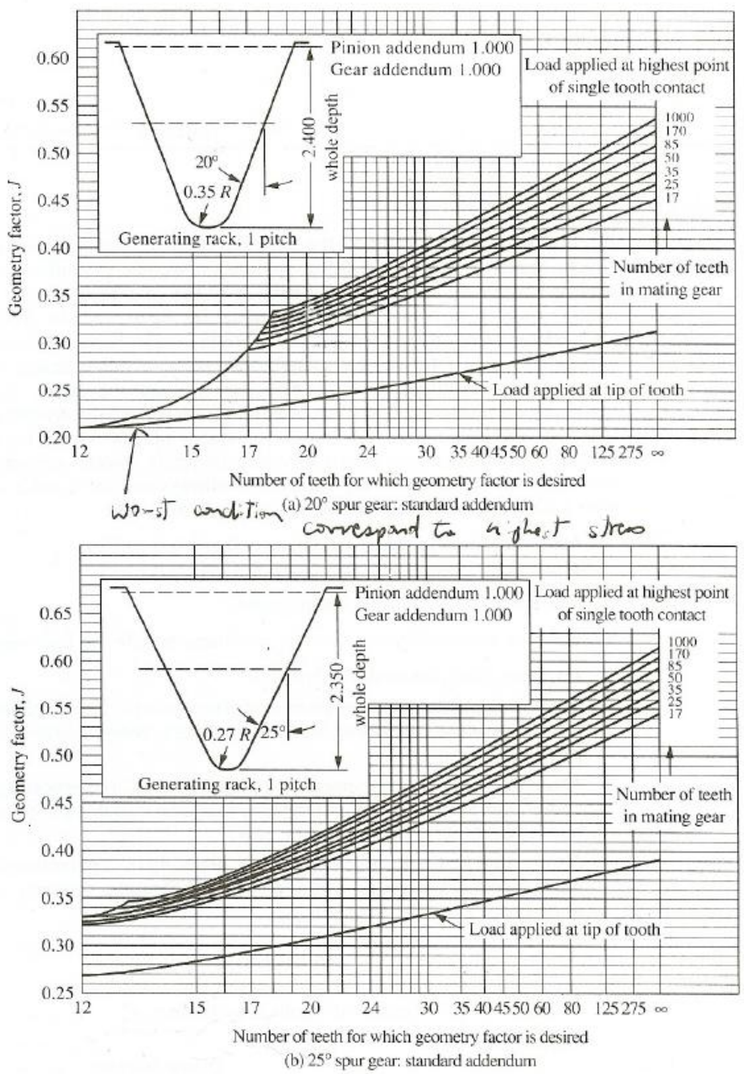

Figure 6: Geometry Factor, (Extracted from *AGMA Standard for Rating the Pitting Resistance and Bending Strength of Spur and Helical Involute Gear Teeth, AGMA 218.01*

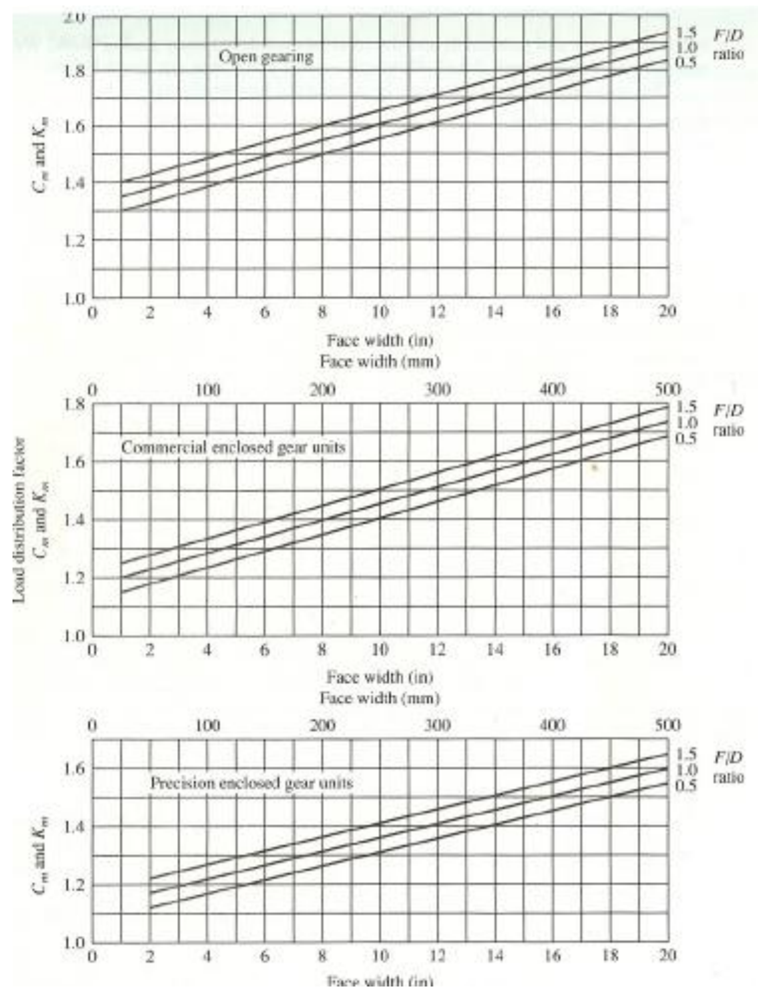

Figure 7: Load Distribution Factor, K_m and C_m

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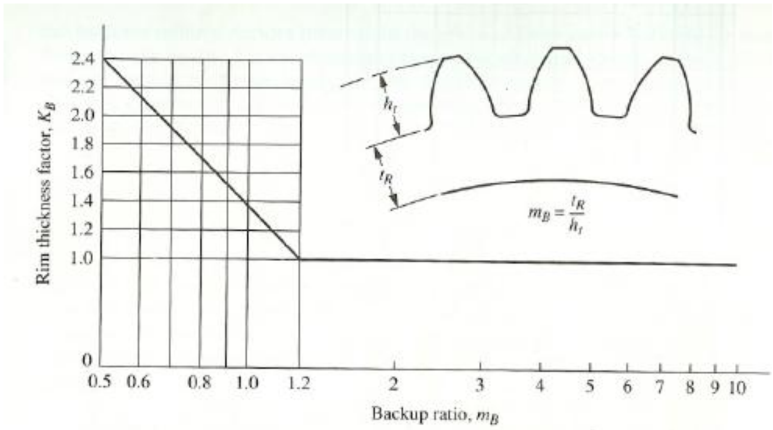

Figure 8 Rim Thickness Factor, K_B

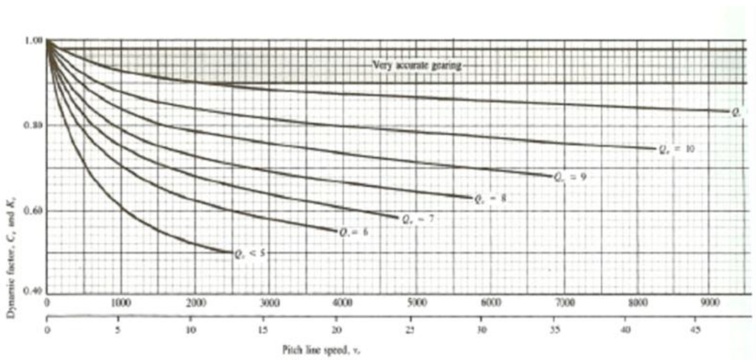

Figure 9: Dynamic Factor C_v and K_v

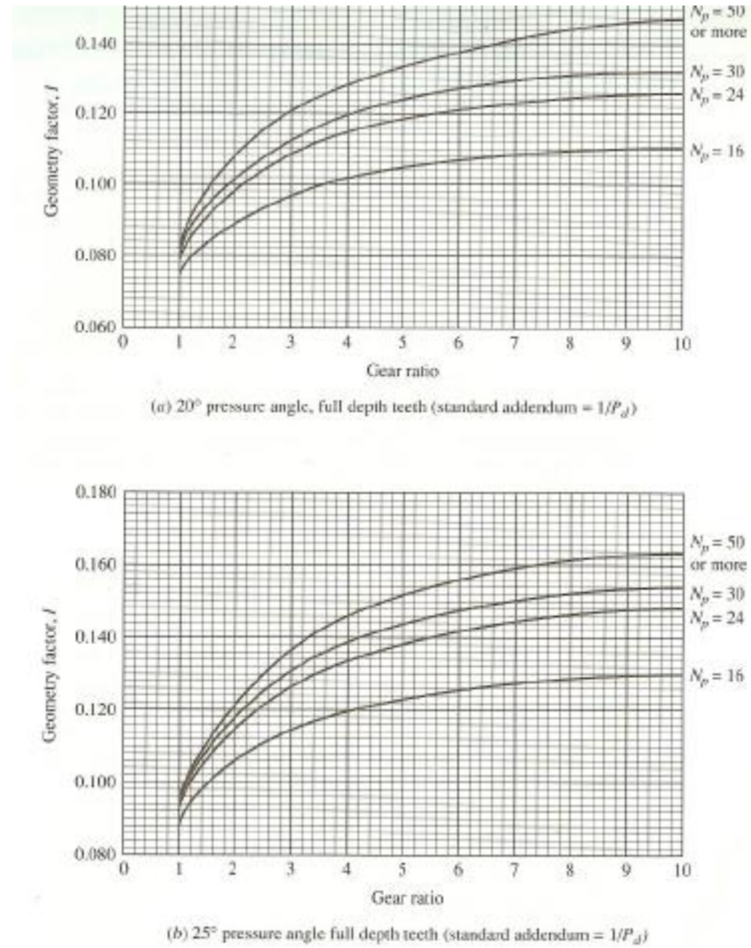

Figure 10: External Spur Pinion Geometry Factor, ***I*,** for Standard Center Distances. All curves are for the lowest point of single tooth contact on the pinion.

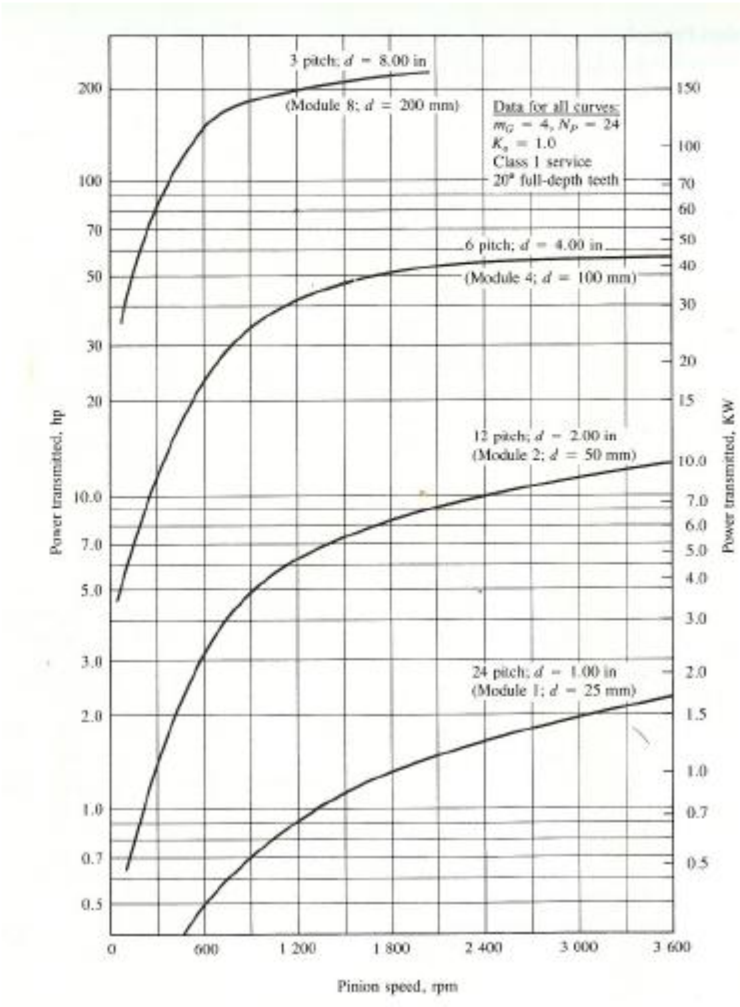

Figure 11: Power vs. Pinion Speed

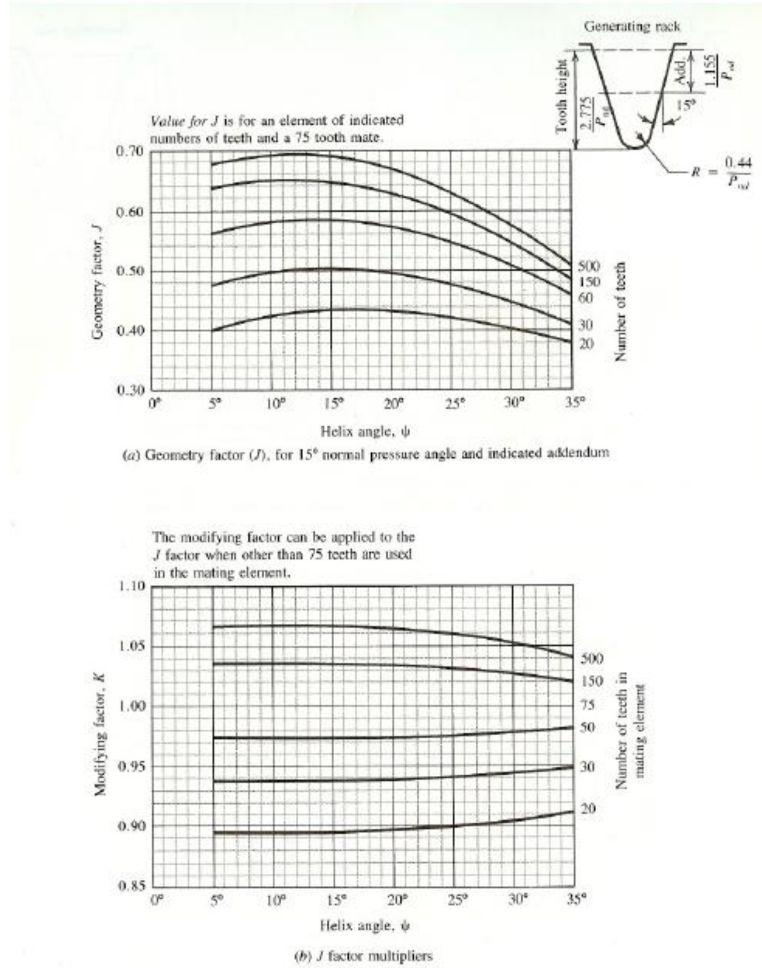

Figure 12: Geometry Factor *J* for 15° Normal Pressure Angle

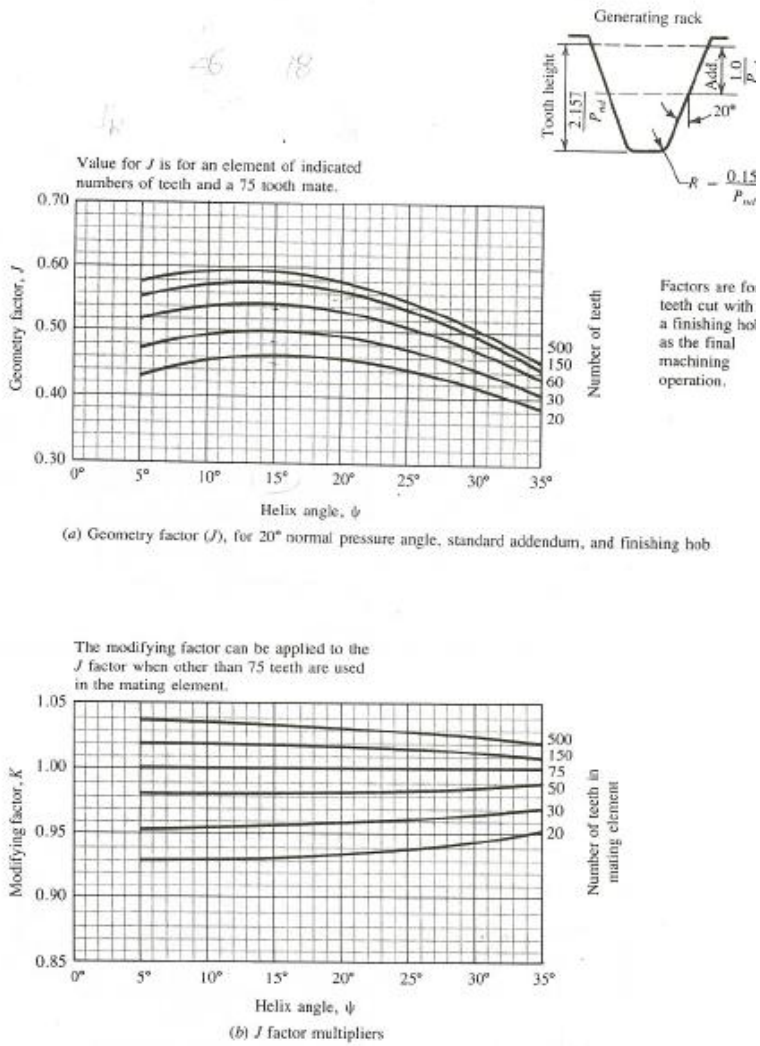

Figure 13: Geometry Factor J for 20° Normal Pressure Angle

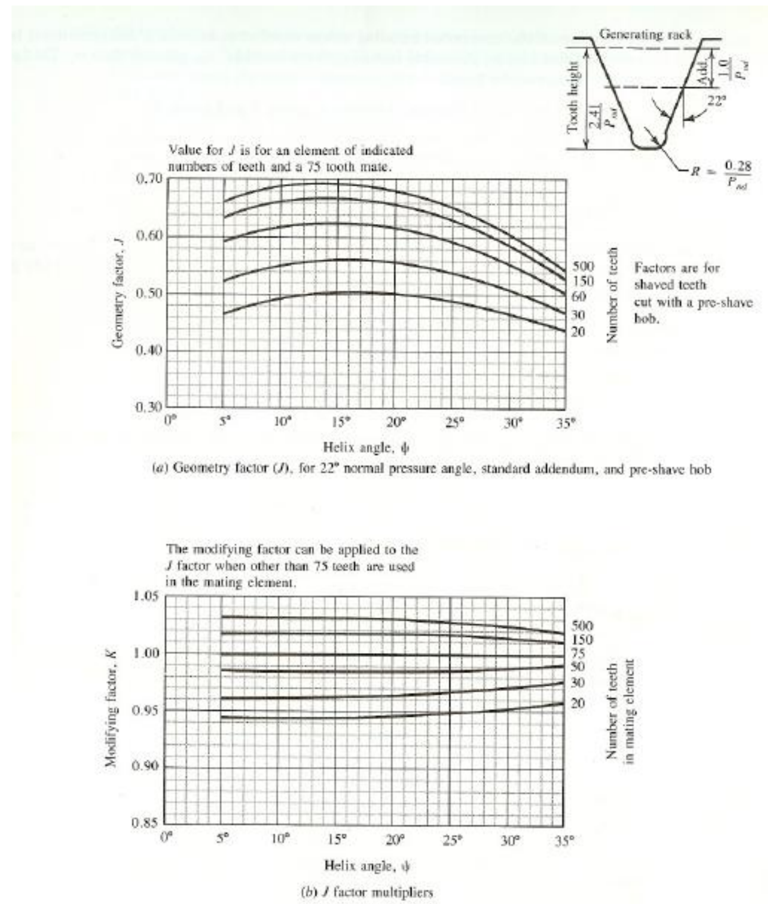

Figure 14 Geometry Factor J for 22° Normal Pressure Angle

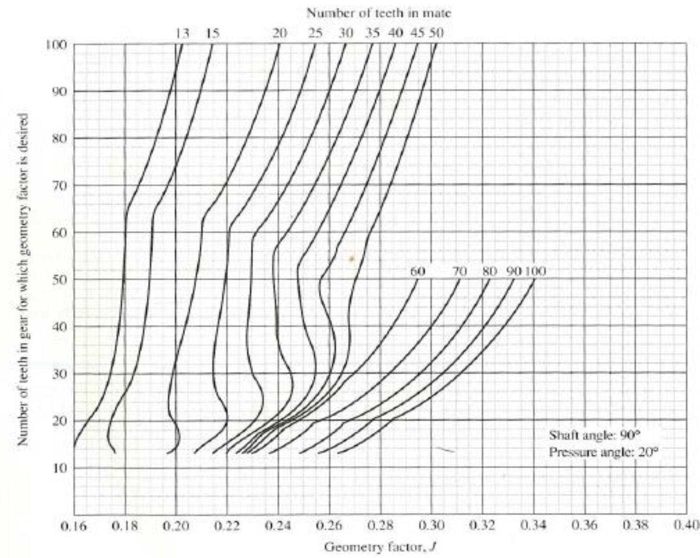

Figure 15 Geometry Factor, *I*, for Straight Bevel Gears with 20° Pressure Angle and *0.120/Pd* Tool Edge Radius

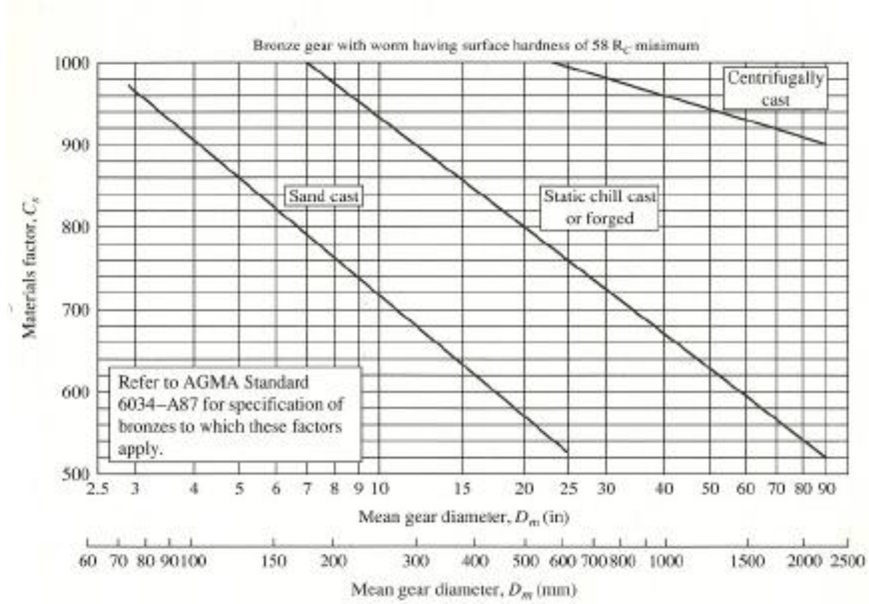

Figure 17 Materials Factor, C_s, for Center Distance> 3.0 in (76 mm) (,

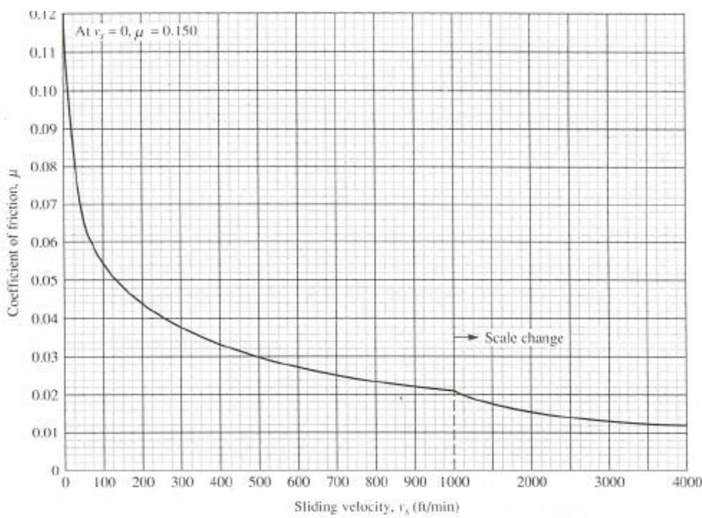

Figure 16 Coefficient of Friction vs. Sliding Velocity for Steel Worm and Bronze Worm Gear

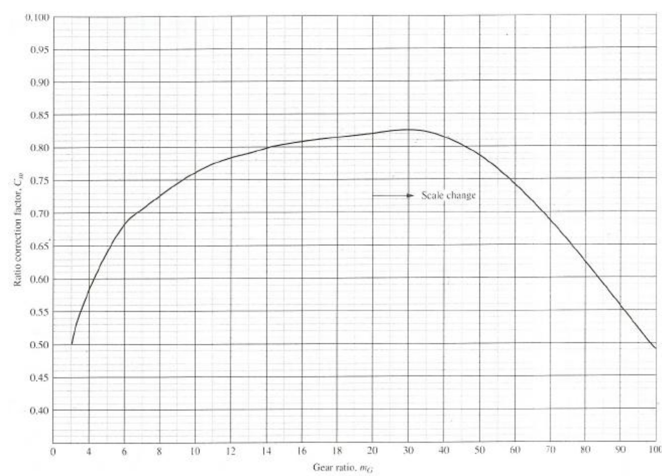

Figure B18 Ratio Correction Factor, C_m, vs. Gear Ratio, m_G

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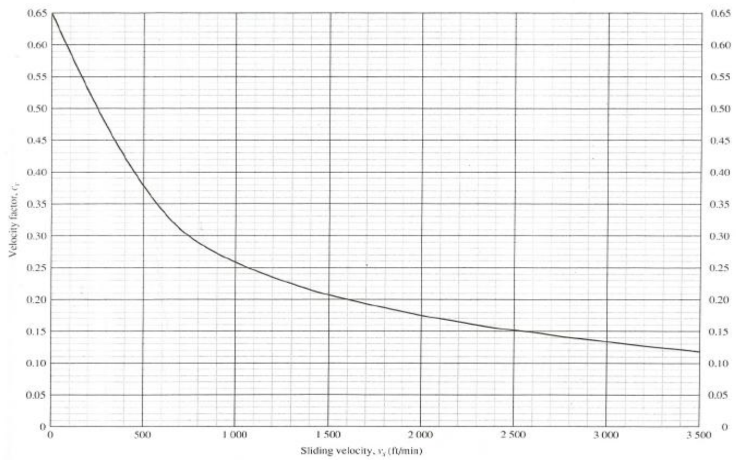

Figure B19 Velocity Factor, C_v, vs. Sliding Velocity

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