LECTURE TWENTY EIGHT

SPUR GEAR DESIGN

References:

Machine Elements in Mechanical Design by Robert L. Mott, P.E. (Chapter 9)

Note: Read chapter 9 (Page 364-448)

Introduction:

In last yaer you studied the difinision of many parameters for spur year in mechanical engineering drawings and as shown on page 2.

Also in this yaer you studied the theory of spur gears in theory of machine and you found the forces on spur gears in machine design in first simister.

Procedure of Desgining a spur gear drive

Follow the steps in example problem (9-5) page 410 with some assumption to make the procedure very simple and the steps are as fallows:

Power transimited = 2.2 KW = 3 hp to pinion
Pinion rotates at = 183.225 rad/sec = 1750 rpm
Gear rotates netween = (48.162 – 48.64) rad/sec = (460 – 465) rpm

Step 1

Choose K_0 = overload factor from table (9-5) page 389.

TABLE 9–5 Suggested overload factors, K_o

	Driven Machine			
Power source	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

Consider uniform driver with heavy shock $K_O = 1.75$

Deign power = 1.75*2.2 = 3.9 KW = 5.25 hp

Now from fig. 9.27 (page 409) determine trial value for diametral pitch P_d or (m)

Try $P_d = 12$ or m = 2 (initial design)

Pinion diameter = $D_p = m\,N_p = \frac{N_p}{P_d} \quad or \quad P_d = \frac{N_p}{D_p} = \frac{N_G}{D_G}$

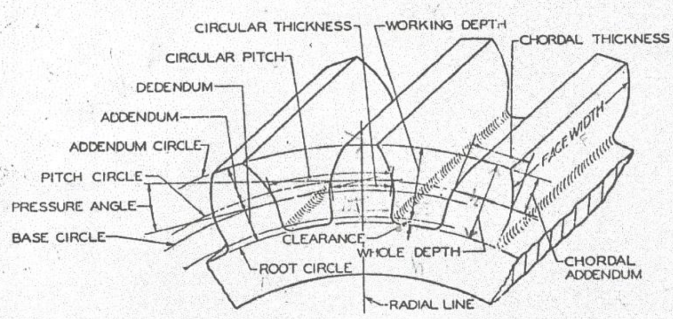
Circular pitch = $P = \frac{\pi D}{N}$

تعاريف الترس الاسطواني العدل

لقد اصبحت تناسبات واشكال التروس مثبته بموجب مواصفات خاصه . والتعاريف المبينه في الجدول والموضحه في الشكل التالي هي عامه لجميع التروس الاسطوانيه العدله .

الابعاد التي تخص ارتفاع السن هي لسن الانفوليوت الذي زاوية الضغط فيه هي 14.5° او 20° .

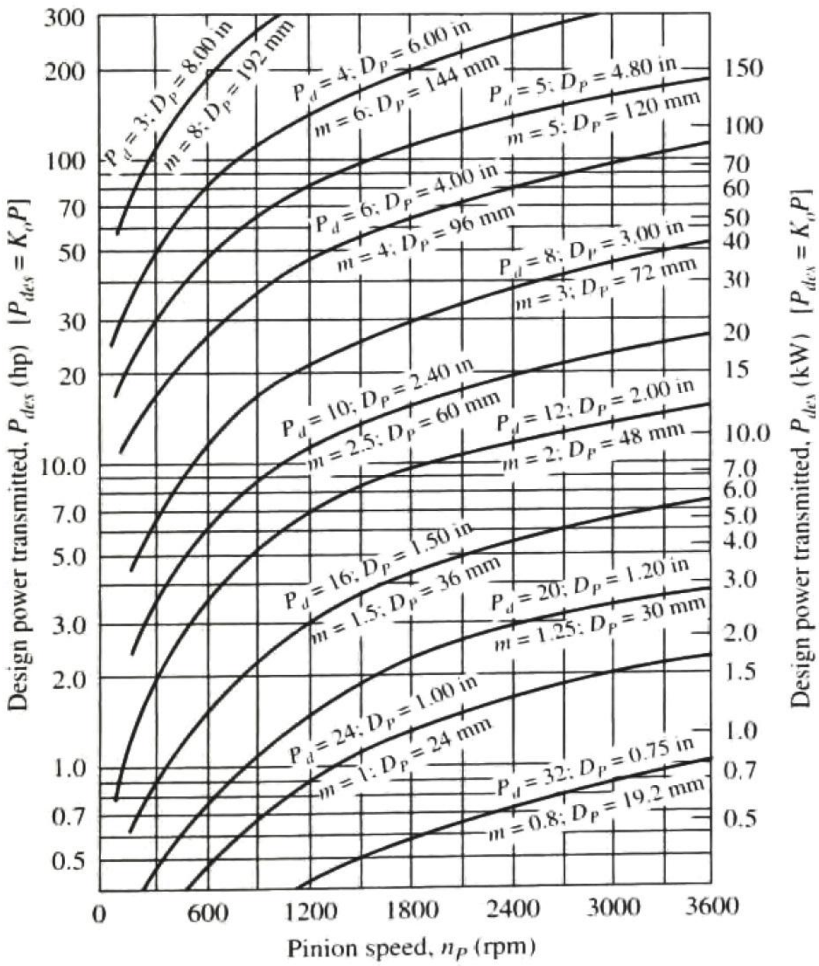
التعريف	الرمز	المصطلح
دائرة وهمية يتم عليها تصميم سن الترس عندما يتعشق ترسان بصورة مرضية فان دائرتي الخطوة فيهما تكونان مماستين .	D	دائرة الخطوة (Pitch circle) D = m N
الدائرة التي تمر خلال قمة الاسنان .	Do	دائرة طرف السن (Addendum circle) Do = D + 2a
الدائرة التي تمر خلال قاعدة الاسنان .	DR	دائرة الجذر (Root circle) DR = D - 2b
عدد الاسنان الموجودة حول المحيط الكامل للترس .	N	عدد الاسنان (Number of teeth) N = D/m
وحدة لقياس اسنان التروس . وهي الكمية الرئيسية في تعين حجم السن . الموديل عبارة عن حاصل قسمة قطر دائرة الخطوة على عدد الاسنان .	m	الموديل (Modul) m = D/N = P/π
المسافة من نقطة على سن الى النقطة المناظرة لها على سن مجاور مقاسه على دائرة الخطوة . اي ترسين متعشقين لهما نفس الخطوة الدائرية .	p	الخطوة الدائرية (Circular pitch) p = πD/N = πm



المعادلة	التعريف	الرمز	المصطلح
tc = D sin(90° / N)	سمك سن مقاس على وتر دائرة الخطوة .	tc	السمك الوتري (Chordal thickness)
	عرض وجه السن .	F	عرض الوجه (Face width)
20° او 14.5°	الزاوية المحصورة بين اتجاه الضغط بين الاسنان المتعشقة وخط مماس لدائرة الخطوة . زاوية الضغط تحدد مقاس دائرة الاساس التي يتولد منها المنحني المنشا (Envolute) .	α	زاوية الضغط (Pressure angle)
$R = n_P / n_G = D_G / D_P = N_G / N_P$	النسبة بين عدد دورات الترس القائد وعدد دورات الترس المقاد .	R	نسبة السرع (Gear ratio)
$n_P = R \cdot n_G$ $N_G = n_P / R$	عدد الدورات التي يدورها الترس في الدقيقة الواحدة .	n	عدد الدورات في الدقيقة (Revolution per minute)
	اصغر الترسين المتعشقين .	P	الترس الصغير (Pinion)
	اكبر الترسين المتعشقين .	G	الترس الكبير (Gear)

المعادلة	التعريف	الرمز	المصطلح
a = m	المسافة الشعاعية من قمة السن الى دائرة الخطوة .	a	طرف السن (Addendum)
b = 1.12 m	المسافة الشعاعية من دائرة الخطوة الى قاعدة السن .	b	عمق جذر السن (Dedendum)
	المسافة الشعاعية من قمة السن الى وتر دائرة الخطوة .	ac	طرف السن الوتري (Chordal addendum)
h = a + b	لارتفاع الكلي للسن .	h	العمق الكلي (Whole depth)
hw = h - c	المسافة التي يسقطها سن الترس على فراغ سن الترس الاخر المعشق معه .	hw	العمق الشغال (Working depth)
c = h - hw	المسافة بين قمة سن وقعر فراغ السن المعشق معه .	c	الخلوص (Clearance)
تستنتج من الرسم	هي الدائرة التي ينشا او يتولد منها المنحني المنشا (Envolute) .	Db	دائرة الاساس (Base circle)
t = P/2 = πm/2	سمك مقاس على دائرة الخطوة .	t	السمك الدائري (Circular thickness)

FIGURE 9–27
Design power transmitted vs. pinion speed for spur gears with different pitches and diameters



For all curves: 20° full depth teeth:
$N_P = 24$; $N_G = 96$; $m_G = 4.00$; $F = 12/P_d$; $Q_v = 6$
Steel gears, HB 300; $s_{at} = 36000$ psi; $s_{ac} = 126000$ psi

Step 2

Specify N_p = No. of teeth in pinion = 17 to 20 (in this problem as a start choose N_p=18)

Step 3

$$V_R = velocity\ ratio = \frac{n_p}{n_g} = \frac{Rotation\ of\ pinion}{Rotation\ of\ gear} = \frac{1750}{462.5} = 3.78$$

Step 4

$$V_R = \frac{N_G}{N_p} \quad \therefore\ N_G = 3.78 * 18 = 68.04 \quad \rightarrow\ N_G = 68\ (Integer)$$

Step 5

$$\text{Actual } V_R = \frac{68}{18} = 3.778$$

Step 6

Actual $n_g = n_p \left[\frac{N_p}{N_G}\right] = 18.225 \frac{rad}{sec} * \frac{18}{68} = 48.49 \; rad/sec$

The above value within the limit given in example $\therefore$ our assumption is **OK**

Step 7

Compute $D_P\ (pitch\ diameter\ of\ pinion) = \frac{N_P}{P_d} = m\, N_p = 1.5\, inch = 38.1\, mm$

$D_G\ (pitch\ diameter\ of\ gear) = \frac{N_G}{P_d} = m\, N_G = 5.667\, inch = 143.9\, mm$

C = center distance = $\frac{N_P + N_G}{Z\, P_d} = \frac{m}{2}\left(N_p + N_G\right) = \frac{18+68}{24} = 3.58\, in = 91\, mm$

$\vartheta_t = pitch\ line\ speed = \pi\, D_P \frac{n_p}{12} = \frac{[\pi*1.5*1750]}{12} = 687 \frac{ft}{min} = 3.49\, m/sec$

$W_t = transmited\ load = \frac{P}{\vartheta_t} = \frac{2.2*1000}{3.49} = 640.5\, N$

$= \frac{33000P}{\vartheta_t} = \frac{33000*3hp}{687} = 144\, Ib$

The above value seems to be acceptable.

Step 8

F = Face width should be between $\frac{8}{P_d} < F < \frac{16}{P_d}$

By using equation (9-28) or $8m < F < 16m$

16.94 mm (0.667in) < F < 33.85 mm (1.33in)

Use this value: F = 25.4 mm (1 inch)

Step 9

Specify C_p = Elastic coefficient from table 4-9 (page 400) for both pinion and gear is steel

$\therefore\ \boldsymbol{C_p = 191\, MPa = 2300\, Ib/in^2}$

TABLE 9–9 Elastic coefficient, C_p

		Gear material and modulus of elasticity, E_G, lb/in² (MPa)					
Pinion material	Modulus of elasticity, E_P, 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)	2300 (191)	2180 (181)	2160 (179)	2100 (174)	1950 (162)	1900 (158)
Mall. iron	25×10^6 (1.7×10^5)	2180 (181)	2090 (174)	2070 (172)	2020 (168)	1900 (158)	1850 (154)
Nod. iron	24×10^6 (1.7×10^5)	2160 (179)	2070 (172)	2050 (170)	2000 (166)	1880 (156)	1830 (152)
Cast iron	22×10^6 (1.5×10^5)	2100 (174)	2020 (168)	2000 (166)	1960 (163)	1850 (154)	1800 (149)
Al. bronze	17.5×10^6 (1.2×10^5)	1950 (162)	1900 (158)	1880 (156)	1850 (154)	1750 (145)	1700 (141)
Tin bronze	16×10^6 (1.1×10^5)	1900 (158)	1850 (154)	1830 (152)	1800 (149)	1700 (141)	1650 (137)

Source: Extracted from AGMA Standard 2001-C95, *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.
Note: Poisson's ratio = 0.30; units for C_p are $(\text{lb/in}^2)^{0.5}$ or $(\text{MPa})^{0.5}$.

Step 10

$K_V = dynamic\ factor$

$Q_V = Quality\ number$

From table 9-2 for certain applications find Q_V, or from pitch line velocity. Then find K_V from fig. 9-21 Page 393.

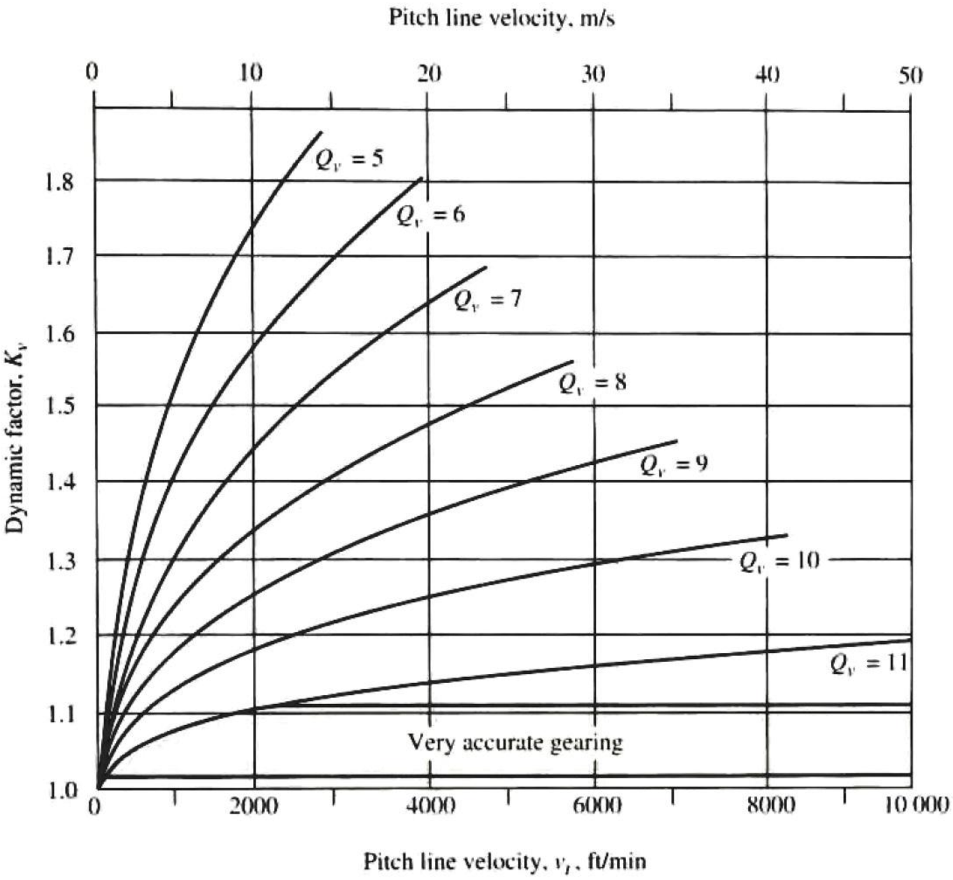
TABLE 9–2 Recommended AGMA quality numbers

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
800–2000	8–10	4–11
2000–4000	10–12	11–22
Over 4000	12–14	Over 22

FIGURE 9–21
Dynamic factor, K_V (Extracted from AGMA 2001-C95 Standard *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)



Step 11

J_p = Bending geometry factor for pinion (should be found from fig. 9-17 (Page 387))
J_G = Bending geometry factor for gear (should be found from fig. 9-17 (Page 387))
I = pitting geometry factor for both pinion & gear (fig. 9-23, Page 402)

Now for this problem:

$J_p = 0.325$, $J_G = 0.41$, $I = 0.104$

For 20° full depth teeth,

FIGURE 9–17
Geometry factor, J (Extract from AGMA 218.01 Standard, *Rating the Pitting Resistance and Bending Strength of Spur and Helical Involute Gear Teeth,* with the permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA 22314)

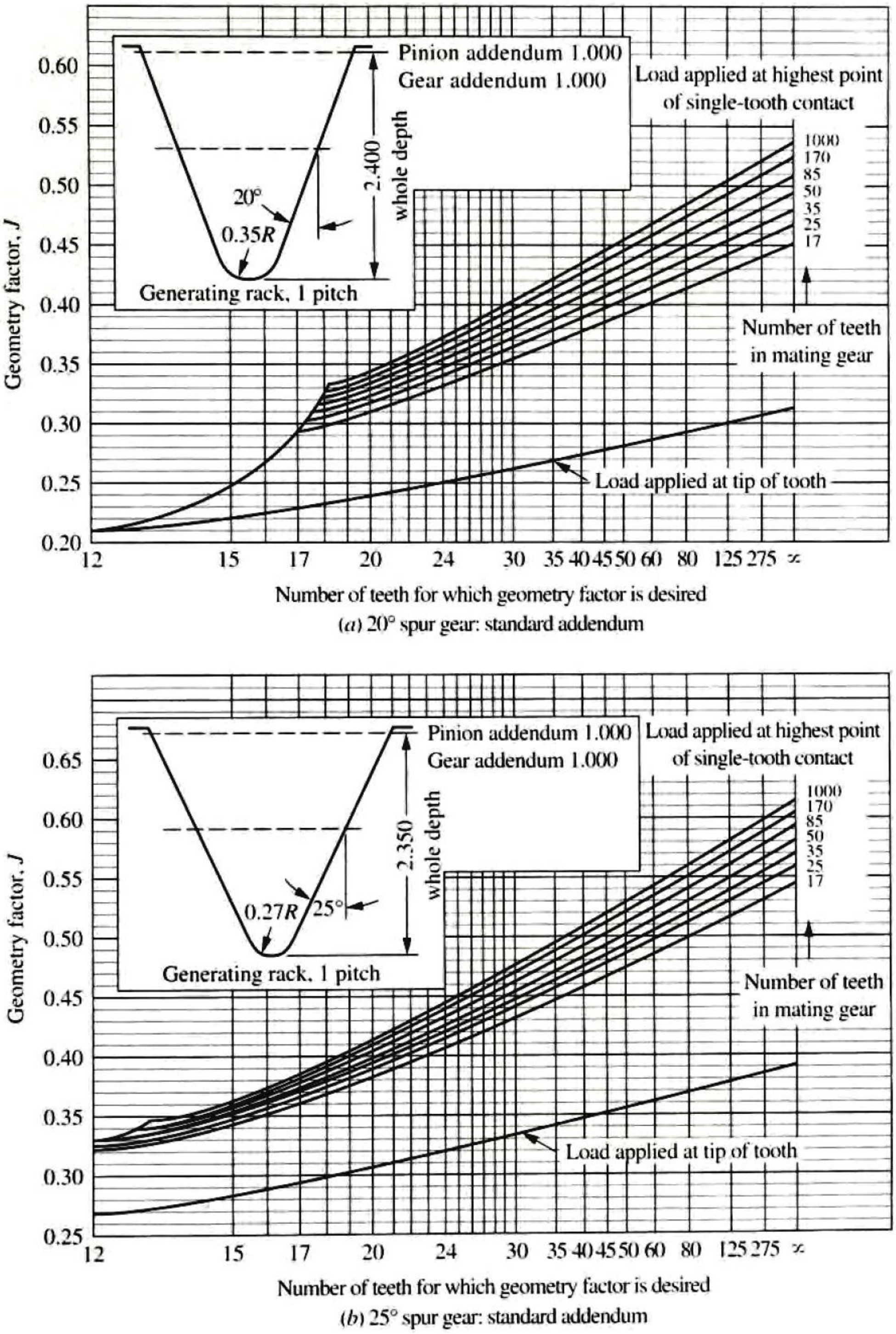
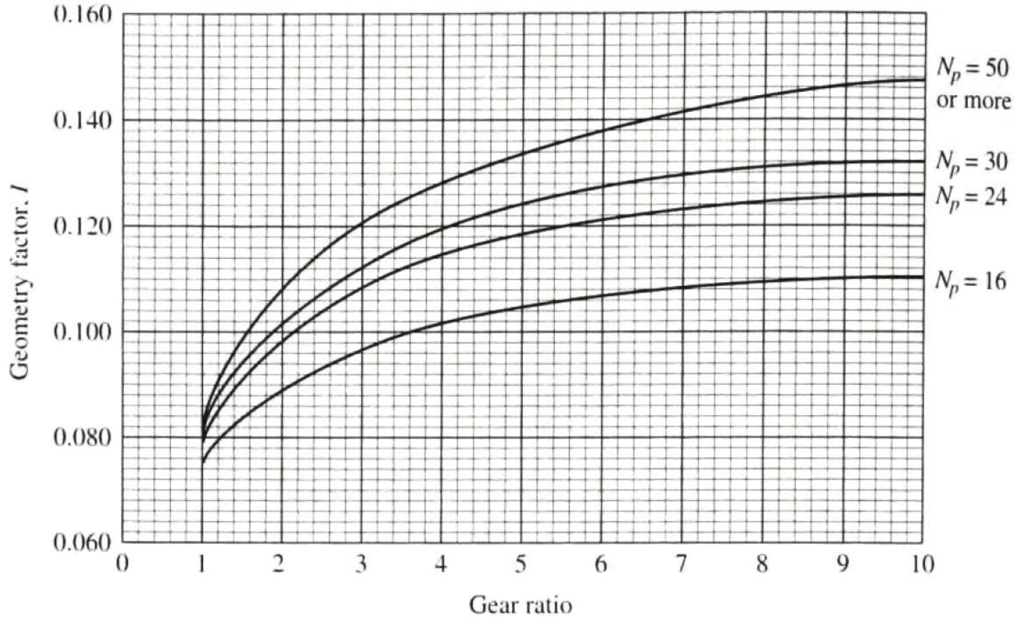
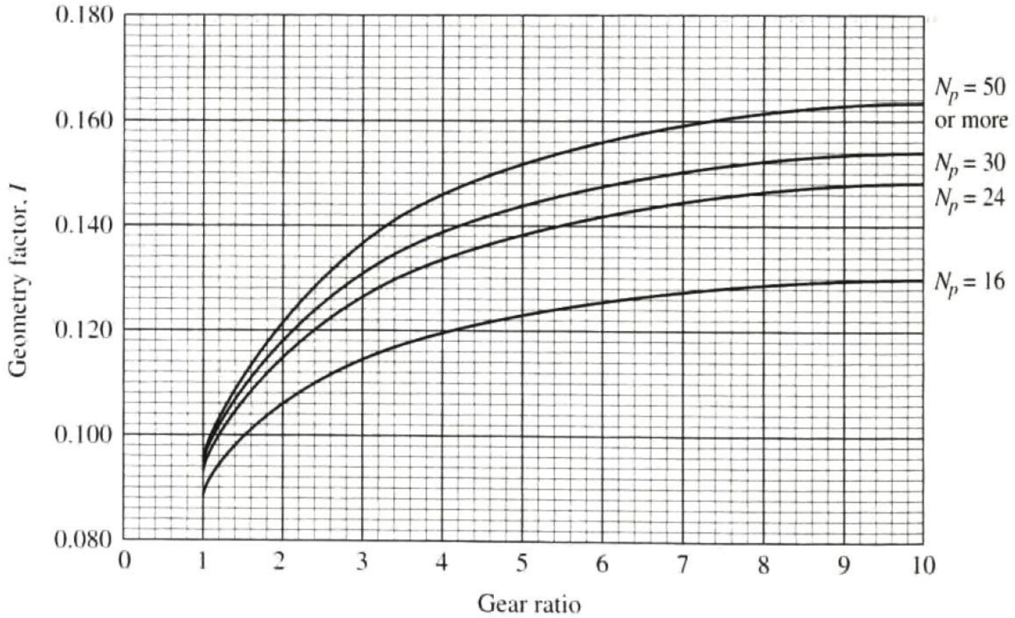


FIGURE 9–23
External spur pinion geometry factor, I, for standard center distances. All curves area for the lowest point of single-tooth contact on the pinion. (Extracted from AGMA Standard 218.01, *Rating the Pitting Resistance and Bending Strength of Spur and Helical Involute Gear Teeth*, with the permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA 22314)



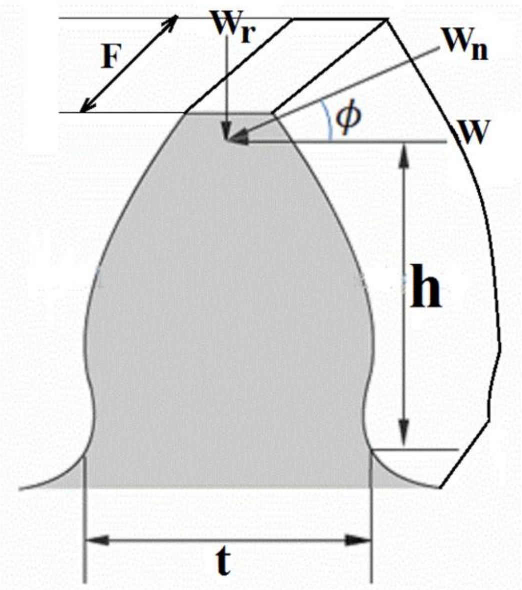
(a) 20° pressure angle, full-depth teeth (standard addendum = $1/P_d$)



(b) 25° pressure angle, full-depth teeth (standard addendum = $1/P_d$)

Step 12

Compute the expected bending stresses in pinion & gear



W = tangential force

F = face width

Ø = pressure angle

S_{t_1} = bending stress = $\frac{M*C}{I} = \frac{W*h*\frac{t}{2}}{F*\frac{t^3}{12}} = \frac{6Wh}{F\,t^2}$

Now Lewise factor Y = $\frac{t^2}{6hP_c}$

$P_c = circular\ pitch = \pi\, m = \frac{\pi}{P_d}$

$\therefore\ S_{t_1} = \frac{W}{F*Y*P_c}$

Now if K_t = stress concentration

$\therefore\ S_{t_2} = K_t\ \frac{W}{F*Y*P_c} = \frac{W}{F*\left(\frac{\pi}{P_d}\right)*\left(\frac{Y}{K_t}\right)} = \frac{W*P_d}{F*\left(\frac{\pi Y}{K_c}\right)} = \frac{W*P_d}{F*J_p}$

Where J = bending geometry factor = $\frac{\pi*Y}{K_c}$

Now the modified equation for bending stress is:

$S_{at} = \frac{W_t*P_d}{F*J} * K_O * K_V$

$\therefore\ S_{at)P} = \frac{144*12}{1*0.325} * 1.75 * 1.35 = 83.8\ MPa = 12.15\ Ksi$

$S_{at)G} = S_{at)P} * \left(\frac{J_P}{J_G}\right) = 66.4\ MPa$

Step 13

Compute $S_{ac} = Expected\ contact\ stress\ in\ pinion\ \&\ gear$

$$= C_p\sqrt{\frac{W_t*K_O*K_V}{F*D_p*I}} = 2300\sqrt{\frac{144*1.75*1.35}{1*1.5*0.104}} = 730.5\ MPa = 110\ Ksi$$

Step 14

From step 12 & step 13 choose the material of pinion & gear. From fig. 9-11 choose HB 250 for both pinion & gear,

((At 110*1000 Ib/in^2 from fig. Brinel hardness No. ≅ 250))

FIGURE 9–10
Allowable bending stress number for through-hardened steel gears, s_{at} (Extracted from AGMA 2001-C95 Standard, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, with permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA 22314)

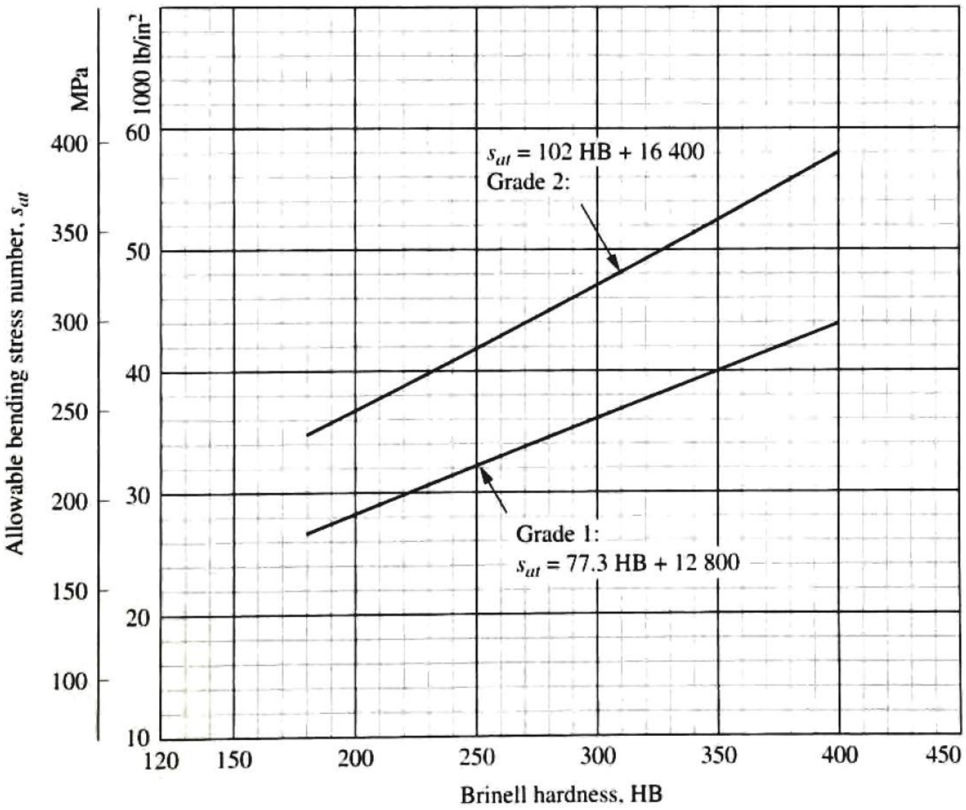


FIGURE 9–11
Allowable contact stress number for through-hardened steel gears, s_{ac} (Extracted from AGMA 2001-C95 Standard, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth*, with permission of the publisher, American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, VA 22314)

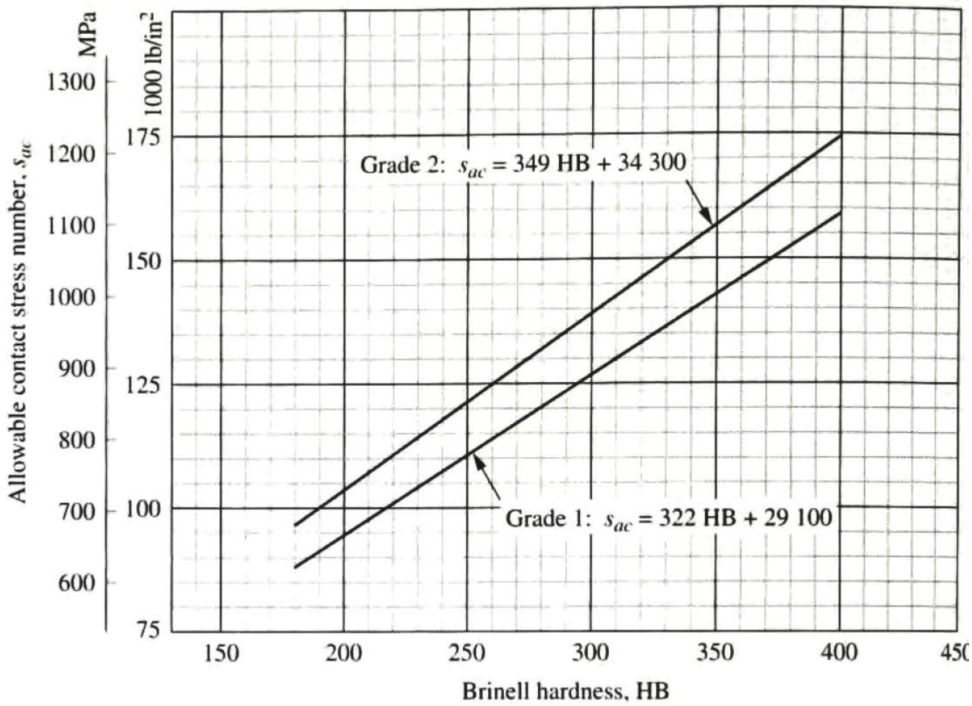


TABLE 9–3 Allowable stress numbers for case-hardened steel gear materials

	Allowable bending stress number, s_{at} (ksi)			Allowable contact stress number, s_{ac} (ksi)		
Hardness at surface	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Flame- or induction-hardened:						
50 HRC	45	55		170	190	
54 HRC	45	55		175	195	
Carburized and case-hardened:						
55–64 HRC	55			180		
58–64 HRC	55	65	75	180	225	275
Nitrided, through-hardened steels:						
83.5 HR15N		See Figure 9–14.		150	163	175
84.5 HR15N		See Figure 9–14.		155	168	180
Nitrided, nitralloy 135M:[a]						
87.5 HR15N		See Figure 9–15.				
90.0 HR15N		See Figure 9–15.		170	183	195
Nitrided, nitralloy N:[a]						
87.5 HR15N		See Figure 9–15.				
90.0 HR15N		See Figure 9–15.		172	188	205
Nitrided, 2.5% chrome (no aluminum):						
87.5 HR15N		See Figure 9–15.		155	172	189
90.0 HR15N		See Figure 9–15.		176	196	216

Source: Extracted from AGMA Standard 2001-C95, *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.

[a]Nitralloy is a proprietary family of steels containing approximately 1.0% aluminum which enhances the formation of hard nitrides.