Table 17-16B Surface Strength Factors Calculation

No.	Item	Symbol	Unit	Pinion	Gear
1	Allowable Hertz Stress	σ_{Hlim}	kgf/mm²	164	
2	Pitch Diameter of Pinion	d_1	mm	40	
3	Effective Tooth Width	b_w		20	
4	Teeth Ratio (z_2/z_1)	u		2	
5	Zone Factor	Z_H		2.495	
6	Material Factor	Z_M	$(kgf/mm^2)^{0.5}$	60.6	
7	Contact Ratio Factor	Z_ε		1.0	
8	Helix Angle Factor	Z_β		1.0	
9	Life Factor	K_{HL}		1.0	
10	Lubricant Factor	Z_L		1.0	
11	Surface Roughness Factor	Z_R		0.90	
12	Sliding Speed Factor	Z_V		0.97	
13	Hardness Ratio Factor	Z_W		1.0	
14	Dimension Factor of Root Stress	K_{HX}		1.0	
15	Load Distribution Factor	$K_{H\beta}$		1.025	
16	Dynamic Load Factor	K_V		1.4	
17	Overload Factor	K_O		1.0	
18	Safety Factor for Pitting	S_H		1.15	
19	Allowable Tangential Force on Standard Pitch Circle	F_{tlim}	kgf	251.9	251.9

17.3 Bending Strength Of Bevel Gears

This information is valid for bevel gears which are used in power transmission in general industrial machines. The applicable ranges are:

Module:	m	1.5 to 25 mm
Pitch Diameter:	d	less than 1600 mm for straight bevel gears less than 1000 mm for spiral bevel gears
Linear Speed:	v	less than 25 m/sec
Rotating Speed:	n	less than 3600 rpm

17.3.1 Conversion Formulas

In calculating strength, tangential force at the pitch circle, F_{tm}, in kgf; power, P, in kW, and torque, T, in kgf.m, are the design criteria. Their basic relationships are expressed in **Equations (17-23)** through **(17-25)**.

$$F_{tm} = \frac{102P}{V_m} = \frac{1.95 \times 10^6 P}{d_m n} = \frac{2000T}{d_m} \quad (17\text{-}23)$$

$$P = \frac{F_{tm} V_m}{102} = 5.13 \times 10^{-7} F_{tm} d_m n \quad (17\text{-}24)$$

$$T = \frac{F_{tm} d_m}{2000} = \frac{974P}{n} \quad (17\text{-}25)$$

where:
V_m : Tangential speed at the central pitch circle
V_m : $\frac{d_m n}{19100}$
d_m : Central pitch circle diameter
d_m : d - bsinδ

17.3.2 Bending Strength Equations

The tangential force, F_{tm}, acting at the central pitch circle should be less than the allowable tangential force, $F_{tm\,lim}$, which is based upon the allowable bending stress σ_{Flim}. That is:

$$F_{tm} \le F_{tm\,lim} \quad (17\text{-}26)$$

The bending stress at the root, σ_F which is derived from F_{tm} should be less than the allowable bending stress σ_{Flim}.

$$\sigma_F \le \sigma_{Flim} \quad (17\text{-}27)$$

The tangential force at the central pitch circle, F_{tmlim} (kgf), is obtained from **Equation (17-28)**.

$$F_{tmlim} = 0.85\cos\beta_m \sigma_{Flim} m b \frac{R_a - 0.5b}{R_a} \frac{1}{Y_F Y_\varepsilon Y_\beta Y_C} \left(\frac{K_L K_{FX}}{K_M K_V K_O}\right) \frac{1}{K_R} \quad (17\text{-}28)$$

where: β_m : Central spiral angle (degrees)
m : Radial module (mm)
R_a : Cone distance (mm)

And the bending strength σ_F (kgf/mm²) at the root of tooth is calculated from **Equation (17-29)**.

$$\sigma_F = F_{tm} \frac{Y_F Y_\varepsilon Y_\beta Y_C}{0.85\cos\beta_m m b} \frac{R_a}{R_a - 0.5b} \left(\frac{K_M K_V K_O}{K_L K_{FX}}\right) K_R \quad (17\text{-}29)$$

17.3.3 Determination of Factors in Bending Strength Equations

17.3.3.A Tooth Width, b (mm)

The term b is defined as the tooth width on the pitch cone, analogous to face width of spur or helical gears. For the meshed pair, the narrower one is used for strength calculations.

17.3.3.B Tooth Profile Factor, Y_F

The tooth profile factor is a function of profile shift, in both the radial and axial directions.

Using the equivalent (virtual) spur gear tooth number, the first step is to determine the radial tooth profile factor, Y_{FO}, from **Figure 17-8** for straight bevel gears and **Figure 17-9** for spiral bevel gears. Next, determine the axial shift factor, K, with **Equation (17-33)** from which the axial shift correction factor, C, can be obtained using **Figure 17-7**. Finally, calculate Y_F by **Equation (17-30)**.

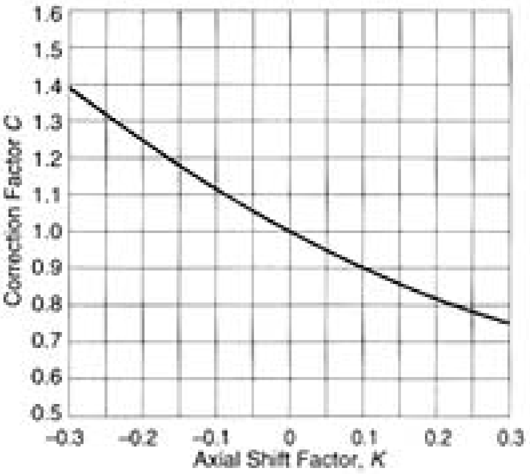

Fig. 17-7 Correction Factor for Axial Shift, C

$$Y_F = C Y_{FO} \quad (17\text{-}30)$$

Should the bevel gear pair not have any axial shift, then the coefficient C is 1, as per **Figure17-7**. The tooth profile factor, Y_F, per **Equation (17-31)** is simply the Y_{FO} This value is from **Figure 17-8** or **17-9**, depending upon whether it is a straight or spiral bevel gear pair. The graph entry parameter values are per **Equation (17-32)**.

$$Y_F = Y_{FO} \qquad (17\text{-}31)$$

$$\left.\begin{aligned} z_v &= \frac{z}{\cos\delta\cos^3\beta_m} \\ x &= \frac{h_a - h_{a0}}{m} \end{aligned}\right\} \qquad (17\text{-}32)$$

where: h_a = Addendum at outer end (mm)

h_{ao} = Addendum of standard form (mm)

m = Radial module (mm)

The axial shift factor, K, is computed from the formula:

$$K = \frac{1}{m}\left\{s - 0.5\pi m - \frac{2(h_a - h_{a0})\tan\alpha_n}{\cos\beta_m}\right\} \qquad (17\text{-}33)$$

17.3.3.C Load Distribution Factor, Y_ε

Load distribution factor is the reciprocal of radial contact ratio.

$$Y\varepsilon = \frac{1}{\varepsilon_\alpha} \qquad (17\text{-}34)$$

The radial contact ratio for a straight bevel gear mesh is:

$$\varepsilon_\alpha = \frac{\sqrt{(R_{va1}^2 - R_{vb1}^2)} + \sqrt{(R_{va2}^2 - R_{vb2}^2)} - (R_{v1} + R_{v2})\sin\alpha}{\pi m\cos\alpha}$$

And the radial contact ratio for spiral bevel gear is:

$$\varepsilon_\alpha = \frac{\sqrt{(R_{va1}^2 - R_{vb1}^2)} + \sqrt{(R_{va2}^2 - R_{vb2}^2)} - (R_{v1} + R_{v2})\sin\alpha_s}{\pi m\cos\alpha_s} \qquad (17\text{-}35)$$

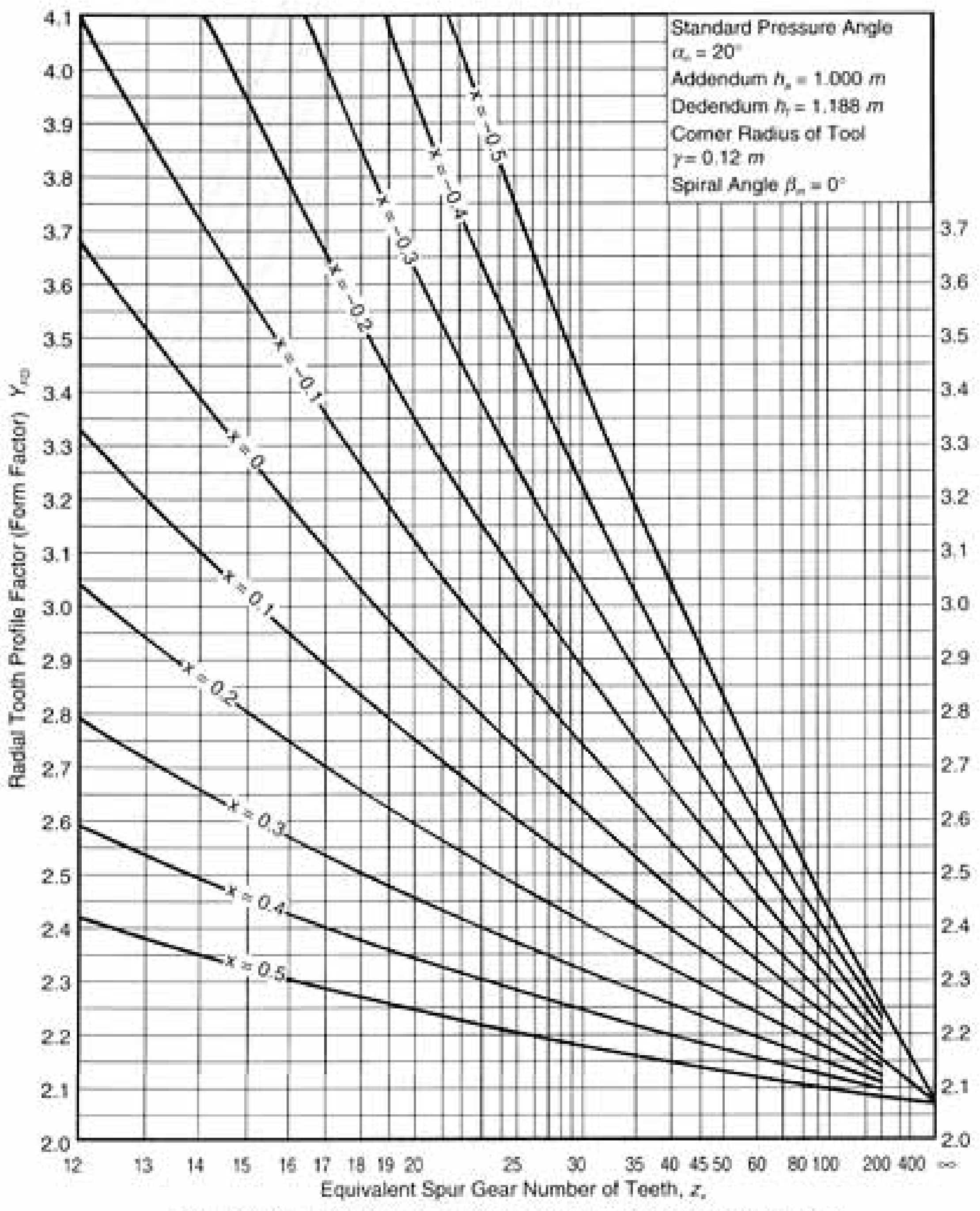

Fig. 17-8 Radial Tooth Profile Factor for Straight Bevel Gear

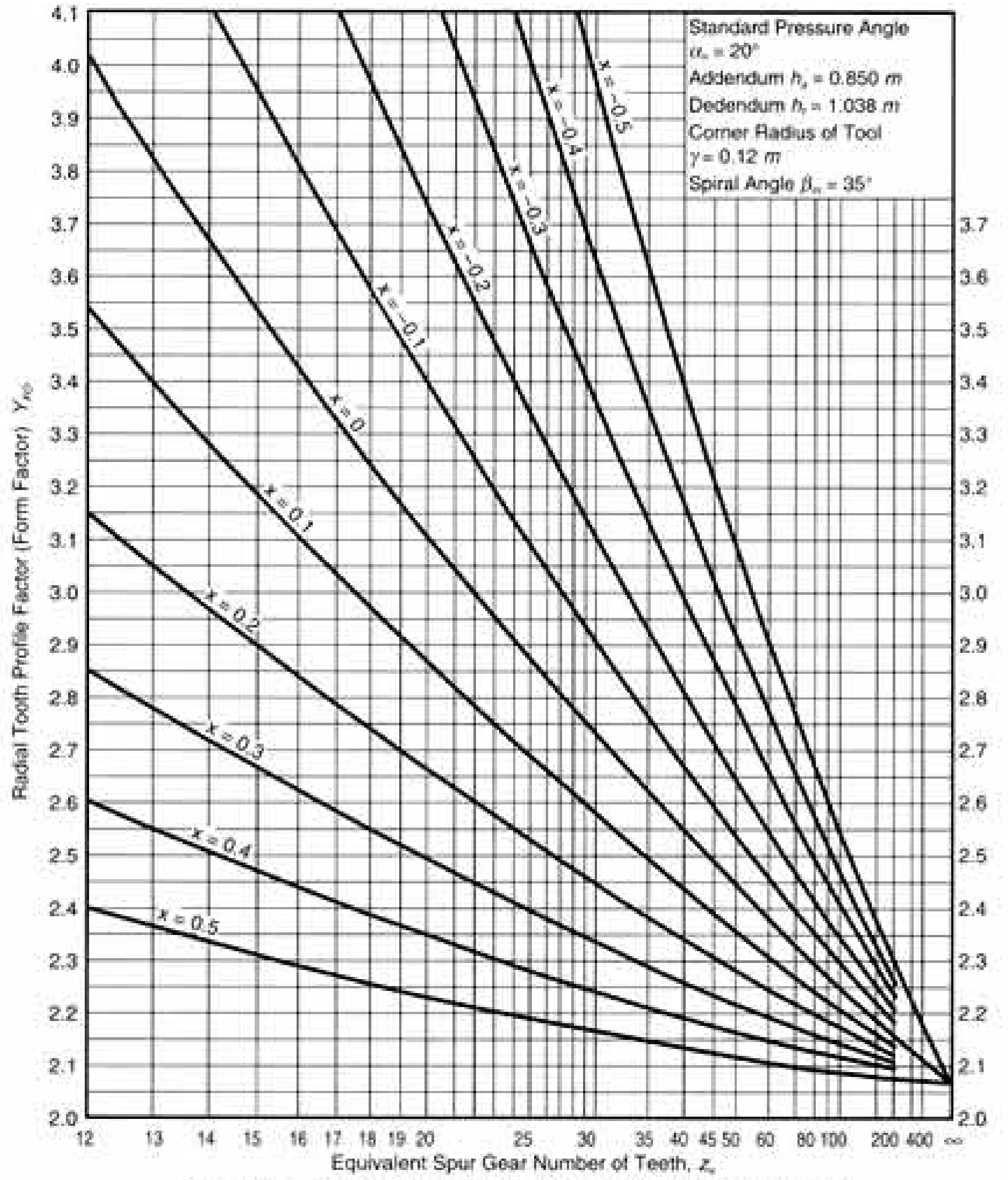

Fig. 17-9 Radial Tooth Profile Factor for Spiral Bevel Gear

See **Table 17-17** through **17-19** for some calculate examples of radial contact ratio for various bevel gear pairs.

Table 17-17 The Radial Contact Ratio for Gleason's Straight Bevel Gear, ε_α

$\Sigma = 90°,\ \alpha = 20°$

z_2 \ z_1	12	15	16	18	20	25	30	36	40	45	60
12	1.514										
15	1.529	1.572									
16	1.529	1.578	1.588								
18	1.528	1.584	1.597	1.616							
20	1.525	1.584	1.599	1.624	1.640						
25	1.518	1.577	1.595	1.625	1.650	1.689					
30	1.512	1.570	1.587	1.618	1.645	1.697	1.725				
36	1.508	1.563	1.579	1.609	1.637	1.692	1.732	1.758			
40	1.506	1.559	1.575	1.605	1.632	1.688	1.730	1.763	1.775		
45	1.503	1.556	1.571	1.600	1.626	1.681	1.725	1.763	1.781	1.794	
60	1.500	1.549	1.564	1.591	1.615	1.668	1.710	1.751	1.773	1.796	1.833

Table 17-18 The Radial Contact Ratio for Standard Bevel Gear, ε_α

$\Sigma = 90°,\ \alpha = 20°$

z_2 \ z_1	12	15	16	18	20	25	30	36	40	45	60
12	1.514										
15	1.545	1.572									
16	1.554	1.580	1.588								
18	1.571	1.595	1.602	1.616							
20	1.585	1.608	1.615	1.628	1.640						
25	1.614	1.636	1.643	1.655	1.666	1.689					
30	1.634	1.656	1.663	1.675	1.685	1.707	1.725				
36	1.651	1.674	1.681	1.692	1.703	1.725	1.742	1.758			
40	1.659	1.683	1.689	1.702	1.712	1.734	1.751	1.767	1.775		
45	1.666	1.691	1.698	1.711	1.721	1.743	1.760	1.776	1.785	1.794	
60	1.680	1.707	1.714	1.728	1.739	1.762	1.780	1.796	1.804	1.813	1.833

Table 17-19 The Radial Contact Ratio for Gleason's Spiral Bevel Gear, ε_α

$\Sigma = 90°,\ \alpha_n = 20°,\ \beta_m = 35°$

z_2 \ z_1	12	15	16	18	20	25	30	36	40	45	60
12	1.221										
15	1.228	1.254									
16	1.227	1.258	1.264								
18	1.225	1.260	1.269	1.280							
20	1.221	1.259	1.269	1.284	1.293						
25	1.214	1.253	1.263	1.282	1.297	1.319					
30	1.209	1.246	1.257	1.276	1.293	1.323	1.338				
36	1.204	1.240	1.251	1.270	1.286	1.319	1.341	1.355			
40	1.202	1.238	1.248	1.266	1.283	1.316	1.340	1.358	1.364		
45	1.201	1.235	1.245	1.263	1.279	1.312	1.336	1.357	1.366	1.373	
60	1.197	1.230	1.239	1.256	1.271	1.303	1.327	1.349	1.361	1.373	1.392

17.3.3.D Spiral Angle Factor, Y_β

The spiral angle factor is a function of the spiral angle. The value is arbitrarily set by the following conditions:

$$\left.\begin{array}{ll} \text{When } 0 \le \beta_m \le 30°, & Y_\beta = 1 - \dfrac{\beta_m}{120} \\ \text{When } \beta_m \ge 30°, & Y_\beta = 0.75 \end{array}\right\} \qquad (17\text{-}36)$$

17.3.3.E Cutter Diameter Effect Factor, Y_C

This factor of cutter diameter, Y_C, can be obtained from **Table 17-20** by the value of tooth flank length, $b / \cos\beta_m$ (mm), over cutter diameter. If cutter diameter is not known, assume Y_C = 1.00.

Table 17-20 Cutter Diameter Effect Factor, Y_C

Types of Bevel Gears	Relative Size of Cutter Diameter			
	∞	6 Times Tooth Width	5 Times Tooth Width	4 Times Tooth Width
Straight Bevel Gears	1.15	—	—	—
Spiral and Zerol Bevel Gears	—	1.00	0.95	0.90

17.3.3.F Life Factor, K_L

We can choose a proper life factor, K_L, from **Table 17-2** similarly to calculating the bending strength of spur and helical gears.

17.3.3.G Dimension Factor of Root Bending Stress, K_{FX}

This is a size factor that is a function of the radial module, m. Refer to **Table 17-21** for values.

Table 17-21 Dimension Factor for Bending Strength, K_{FX}

Radial Module at Outside Diameter, m	Gears Without Hardened Surface	Gears With Hardened Surface
1.5 to 5	1.0	1.0
above 5 to 7	0.99	0.98
above 7 to 9	0.98	0.96
above 9 to 11	0.97	0.94
above 11 to 13	0.96	0.92
above 13 to 15	0.94	0.90
above 15 to 17	0.93	0.88
above 17 to 19	0.92	0.86
above 19 to 22	0.90	0.83
above 22 to 25	0.88	0.80

17.3.3.H Tooth Flank Load Distribution Factor, K_M

Tooth flank load distribution factor, K_M, is obtained from **Table 17-22** or **Table 17-23**.

Table 17-22 Tooth Flank Load Distribution, K_M, for Spiral Bevel Gears, Zerol Bevel Gears and Straight Bevel Gears with Crowning

Stiffness of Shaft, Gear Box, etc.	Both Gears Supported on Two Sides	One Gear Supported on One End	Both Gears Supported on One End
Very Stiff	1.2	1.35	1.5
Average	1.4	1.6	1.8
Somewhat Weak	1.55	1.75	2.0

Table 17-23 Tooth Flank Load Distribution Factor, K_M, for Straight Bevel Gears without Crowning

Stiffness of Shaft, Gear Box, etc.	Both Gears Supported on Two Sides	One Gear Supported on One End	Both Gears Supported on One End
Very Stiff	1.05	1.15	1.35
Average	1.6	1.8	2.1
Somewhat Weak	2.2	2.5	2.8

17.3.3.I Dynamic Load Factor, K_V

Dynamic load factor, K_V, is a function of the precision grade of the gear and the tangential speed at the outer pitch circle, as shown in **Table 17-24**.

Table 17-24 Dynamic Load Factor, K_V

Precision Grade of Gears from JIS B 1702	Tangential Speed at Outer Pitch Circle (m/s)						
	Up to 1	Above 1 to 3	Above 3 to 5	Above 5 to 8	Above 8 to 12	Above 12 to 18	Above 18 to 25
1	1.0	1.1	1.15	1.2	1.3	1.5	1.7
2	1.0	1.2	1.3	1.4	1.5	1.7	
3	1.0	1.3	1.4	1.5	1.7		
4	1.1	1.4	1.5	1.7			
5	1.2	1.5	1.7				
6	1.4	1.7					

17.3.3.J Overload Factor, K_O

Overload factor, K_O, can be computed from **Equation (17-11)** or obtained from **Table 17-4**, identical to the case of spur and helical gears.

17.3.3.K Reliability Factor, K_R

The reliability factor should be assumed to be as follows:

1. General case: K_R=1.2
2. When all other factors can be determined accurately: K_R= 1.0
3. When all or some of the factors cannot be known with certainty: K_R = 1.4

17.3.3.L Allowable Bending Stress at Root, σ_{Flim}

The allowable stress at root σ_{Flim} can be obtained from **Tables 17-5** through **17-8**, similar to the case of spur and helical gears.