10.2 Calculation for Bevel gear strength

Calculation formula of Bending strength for Bevel gear JGMA 403-01 (1976)
Calculation formula of Surface durability (Pitting resistance) for Bevel gear JGMA 404-01 (1977)

1. Application range (common)

1.1 This standard applies to Bevel gears (1) for power transfer used in the general industrial machinery with the following range.

Outer transverse module	: 1.5 ～ 25 mm
Outer pitch diameter	: Below 1,600 mm (For Straight bevel gear) Below 1,000 mm (For Spiral bevel gear)
Outer circumferential velocity	: Below 25 m/s
Revolving velocity	: Below 3,600 min^{-1}
Shaft angle	: 90°
Mean spiral angle	: Below 35°

Facewidth
For Maximum Facewidth, choose the smaller value from either 0.3 times of Cone distance or 10 times of Outer transverse module. However for Zerol® Bevel gear, it is 0.25 times of Outer cone distance.
Ⓡ mark is Gleason Works Trademark.

Tooth profile
Normal reference pressure angles are 20°, 22.5° and 25°.

Accuracy
Accuracy of Bevel gear is defined in JIS B1704 class 1 to 6.

Note (1) This standard is for Straight, Spiral and Zerol bevel gears.

1.2.1. Use this standard for calculation of Bending of Bevel gear for Allowable load as defined above in 1.1 and to determine gear dimensions based on Tooth root bending stress.

1.2.2 This standard used for calculation of tooth flank of allowable load for Straight, Spiral bevel gears and determines gear dimension based on Hertz stress of tooth flank.

2 Definition

2.1 Bending strength
Bending allowable load of Bevel gear is stipulated as Nominal allowable tangential load on the Mean pitch circle based on Allowable tooth root bending stress for each gear when transferring power during operation.

2.2 Surface durability
Surface durability of Bevel gear is stipulated as load capacity that is necessary to provide sufficient safety to the gear against progressive pitting.
Therefore, Allowable load on Bevel gear flank is stipulated as Allowable tangential load on the Mean pitch circle based on Surface durability for each gear when transferring power during operation.

3. Basic formula

For calculating gear strength, conversion formulas are related to calculating Nominal tangential load on the Reference pitch circle. Nominal power and torque are as follows.

3.1 Nominal tangential load on the Mean pitch circle F_{tm}(kgf)

$$F_{tm} = \frac{102P}{v_m} = \frac{1.95\times10^6 P}{d_m n} \qquad (1)$$

Hereby
- P : Nominal power (kW)
- v_m : Circumferential velocity (m/s) on the Mean pitch circle
- d_m : Mean pitch diameter (mm)
- n : Revolving velocity (min^{-1})

$$v_m = \frac{d_m n}{19100} \qquad (2)$$

$$d_m = d - b\sin\delta \qquad (3)$$

Hereby
- d : Pitch diameter (mm)
- δ : Pitch angle (°)

Or $$F_{tm} = \frac{2000T}{d_m} \qquad (4)$$

Hereby
- T : Nominal torque (kgf・m)

3.2 Nominal power P (kW)

$$P = \frac{F_{tm} v_m}{102} = 5.13\times10^{-7} F_{tm} d_m n \qquad (5)$$

3.3 Nominal torque T (kg・m)

$$T = \frac{F_{tm} d_m}{2000} \quad \cdots\cdots (6)$$

Or $$T = \frac{974P}{n} \quad \cdots\cdots (7)$$

4. Calculation formula for gear strength

4.1 Calculation for Bending strength

When calculating Bending strength, use Nominal tangential load on the Mean pitch circle as reference. Therefore Nominal tangential load on the Mean pitch circle should be equal or less than Allowable tangential load on the Mean pitch circle calculated by Allowable tooth root stress. That is to say,

$$F_{tm} \leqq F_{tm\mathrm{lim}} \quad \cdots\cdots (8)$$

Hereby

- F_{tm} : Nominal tangential load on the Mean pitch circle (kgf)
- $F_{tm\mathrm{lim}}$: Nominal allowable tangential load (kgf) on the Mean pitch circle is selected from its smaller value from either pinion or gear.

On the other hand, Tooth root stress obtained from Nominal tangential load on the Mean pitch circle should be equal or lesser than Allowable Tooth root bending stress.

Therefore

$$\sigma_F \leqq \sigma_{F\mathrm{lim}} \quad \cdots\cdots (9)$$

Hereby

- σ_F : Tooth root stress (kgf/mm^2) from Nominal tangential load on the Mean pitch circle.
- $\sigma_{F\mathrm{lim}}$: Allowable Tooth root bending stress (kgf/mm^2)

4.1.1 Calculation for Allowable tangential load on the Mean pitch circle is as follow.

$$F_{tm\mathrm{lim}} = 0.85\cos\beta_m \sigma_{F\mathrm{lim}} mb \frac{R_e - 0.5b}{R_e} \frac{1}{Y_F Y_\varepsilon Y_\beta Y_C} \times \left(\frac{K_L K_{FX}}{K_M K_V K_O}\right) \frac{1}{K_R} \quad \cdots\cdots (10)$$

Hereby

- β_m : Mean spiral angle (°)
- m : Outer transverse module (mm)
- b : Facewidth (mm)
- R_e : Cone distance (mm)
- Y_F : Form factor
- Y_ε : Load distribution factor
- Y_β : Spiral angle factor
- Y_c : Cutter diameter influence factor
- K_L : Life factor
- K_{FX}: Dimension factor for Tooth root stress
- K_M : Load distributed factor for Tooth trace
- K_v : Dynamic factor
- K_0 : Overload factor
- K_R : Reliability factor for Tooth root bending damage

4.1.2 Calculation for Tooth root bending stress is as follow.

$$\sigma_F = F_{tm} \frac{Y_F Y_\varepsilon Y_\beta Y_C}{0.85\cos\beta_m mb} \frac{R_e}{R_e - 0.5b} \left(\frac{K_M K_V K_O}{K_L K_{FX}}\right) K_R \quad \cdots\cdots (11)$$

4.2 Calculation for Tooth root strength

Nominal tangential load on the Mean pitch circle is necessary as reference for calculating Surface strength. Therefore, Nominal tangential load on the Mean pitch circle should be equal or below Allowable tangential load on the Mean pitch circle, which is derived from calculating Allowable Hertz stress. Therefore,

$$F_{tm} \leqq F_{tm\mathrm{lim}} \quad \cdots\cdots (12)$$

Hereby

- F_{tm} : Nominal tangential load on the Mean pitch circle (kgf)
- F_{tmlim} : Calculate Allowable tangential load (kgf) on the Mean pitch circle by selecting the smaller Allowable tangential load (kgf) from either pinion or gear.

On the other hand, Hertz stress based on Nominal tangential load on the Mean pitch circle should be equal or less than Allowable hertz stress.

Therefore

$$\sigma_H \leqq \sigma_{H\mathrm{lim}} \quad \cdots\cdots (13)$$

Hereby

- σ_H : Hertz stress (kgf/mm^2) from Nominal tangential load on the Mean pitch circle
- $\sigma_{H\mathrm{lim}}$: Allowable hertz stress (kgf/mm^2)

4.2.1 Calculation for Allowable tangential load on the Mean pitch circle is as follow.

$$F_{tm\mathrm{lim}} = \left(\frac{\sigma_{H\mathrm{lim}}}{Z_M}\right)^2 \frac{d_1}{\cos\delta_1} \frac{R_e - 0.5b}{R_e} \bullet b \frac{u^2}{u^2+1} \left(\frac{K_{HL} Z_L Z_R Z_V Z_W K_{HX}}{Z_H Z_\varepsilon Z_\beta}\right)^2 \frac{1}{K_{H\beta} K_V K_O} \frac{1}{C_R^2} \quad \cdots\cdots (14)$$

Hereby

- d_1 : Outer pitch diameter for pinion (mm)
- b : Facewidth (mm)
- u : Gear ratio
- R_e : Cone distance (mm)
- Z_H : Zone factor
- Z_M : Elasticity factor
- Z_ε : Contact ratio factor
- Z_β : Spiral angle factor for Surface durability
- K_{HL} : Life factor for Surface Durability
- Z_L : Lubricating oil factor
- Z_R : Roughness factor
- Z_V : Lubricating speed factor
- Z_W : Work hardening factor
- Z_{HX} : Dimension factor for Surface durability
- $K_{H\beta}$: Face load for contact stress for Surface durability
- K_V : Dynamic factor

K_O : Overload factor

C_R : Reliability factor for Surface durability

4.2.2 Calculation for Hertz stress is as follow.

$$\sigma_H = \sqrt{\frac{\cos\delta_1 F_{tm}}{d_1 b}\frac{u^2+1}{u^2}\frac{R_e}{R_e-0.5b}\frac{Z_H Z_M Z_\varepsilon Z_\beta}{K_{HL} Z_L Z_R Z_V Z_W K_{HX}}} \times \sqrt{K_{H\beta} K_V K_O C_R} \quad \cdots\cdots (15)$$

5 Calculation method for factors

5.1 Calculation method for factors based on Bending (tooth root) strength of Bevel gear.

Factors used in calculation formulas for Bending (tooth root) strength as mentioned above are stipulated as follows.

5.1.1 Facewidth b

Facewidth b is stipulated as Facewidth on Pitch cone. For different Facewidth, use narrower side from either pinion or gear as Effective facewidth.

5.1.2 Form Y_F

Obtain Form factor from Fig. 1 and 2.

(a) Refer to Table 1, items 5 and 6 where Normal reference pressure angle is 20°.

Use Form factor graphs in Fig. 2 and 3 to obtain primary value of Y_{FO} (Value of Form factor by Rack shift). Then obtain Revision factor C using Horizontal rack shift from Fig. 1.

$$Y_F = CY_{F0} \quad \cdots\cdots (16)$$

Calculate Y_F from formula $Y_F = CF_{Y0}$. However, Tooth profile with no Horizontal rack shift to be $Y_F = Y_{F0}$.

a.1 Refer to Table 1 for lists of Form factor chart.

Calculate Virtual number of teeth of spur gear Z_υ and Rack shift coefficient x using following formula.

$$z_\upsilon = \frac{z}{\cos\delta\cos^3\beta_m} \quad \cdots\cdots (17)$$

Hereby

δ : Pitch angle (°)

$$x = \frac{h_a - h_{a0}}{m} \quad \cdots\cdots (18)$$

Hereby

h_a : Outer addendum (mm)

h_{ao} : Refer to Table 1 for Reference profile addendum (mm)

m : Outer transverse module (mm)

a. 2. For Bevel gear with tip of cutter with γ about 0.375 mm, constant 0.85 to be changed to 1.0 in the formulas for Allowable tangential load and Bending stress. (Refer to 4.1.1 of standard $\sigma_{F\lim}$).

a. 3. Calculate Horizontal rack shift coefficient K in Fig. 1 using the following formula.

$$K = \frac{1}{m}\left\{s - 0.5\pi m - \frac{2(h_a - h_{a0})\tan\alpha_n}{\cos\beta_m}\right\} \quad \cdots\cdots (19)$$

Hereby

s : Outer transverse circular thickness (mm)

h_a, h_{ao} and m : Same as formula (14).

However the above formula for K is inapplicable for an Isothermal full depth gear tooth.

Fig. 1 Revision factor base on Horizontal Rack shift

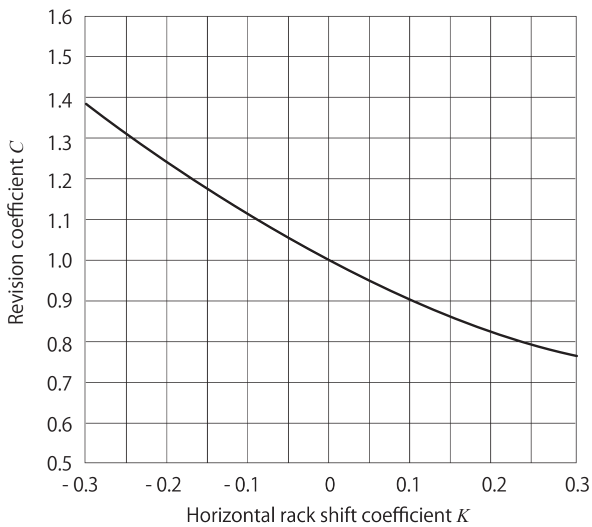


Table 1. Table for Form factor

<table>
<tr><th rowspan="2">Item No.</th><th colspan="6">Transverse reference profile (Transverse tooth thickness : 0.5πm)</th><th rowspan="2">Mean spiral angle
βm</th></tr>
<tr><th>Normal reference pressure angle
αn</th><th>Tooth depth (heel)
h</th><th>Addendum (heel)
ha0</th><th>Dedendum (heel)
hf0</th><th>Bottom clearance (heel)
c</th><th>Cutter tip radius (normal)
r</th></tr>
<tr><td>1</td><td rowspan="6">20°</td><td rowspan="5">1.888m</td><td rowspan="5">0.850m</td><td rowspan="5">1.038m</td><td rowspan="6">0.188m</td><td rowspan="6">0.12m</td><td>15°</td></tr>
<tr><td>2</td><td>20°</td></tr>
<tr><td>3</td><td>25°</td></tr>
<tr><td>4</td><td>30°</td></tr>
<tr><td>5</td><td>35°</td></tr>
<tr><td>6</td><td>2.188m</td><td>1.000m</td><td>1.188m</td><td>0°</td></tr>
<tr><td>7</td><td rowspan="2">22.5°</td><td>1.888m</td><td>0.850m</td><td>1.038m</td><td rowspan="2">0.188m</td><td rowspan="2">0.12m</td><td>35°</td></tr>
<tr><td>8</td><td>1.788m</td><td>0.800m</td><td>0.988m</td><td>0°</td></tr>
<tr><td>9</td><td rowspan="2">25°</td><td>1.888m</td><td>0.850m</td><td>1.038m</td><td rowspan="2">0.188m</td><td rowspan="2">0.12m</td><td>35°</td></tr>
<tr><td>10</td><td>1.788m</td><td>0.800m</td><td>0.988m</td><td>0°</td></tr>
</table>

Fig. 2 Form factor graph (No.6)

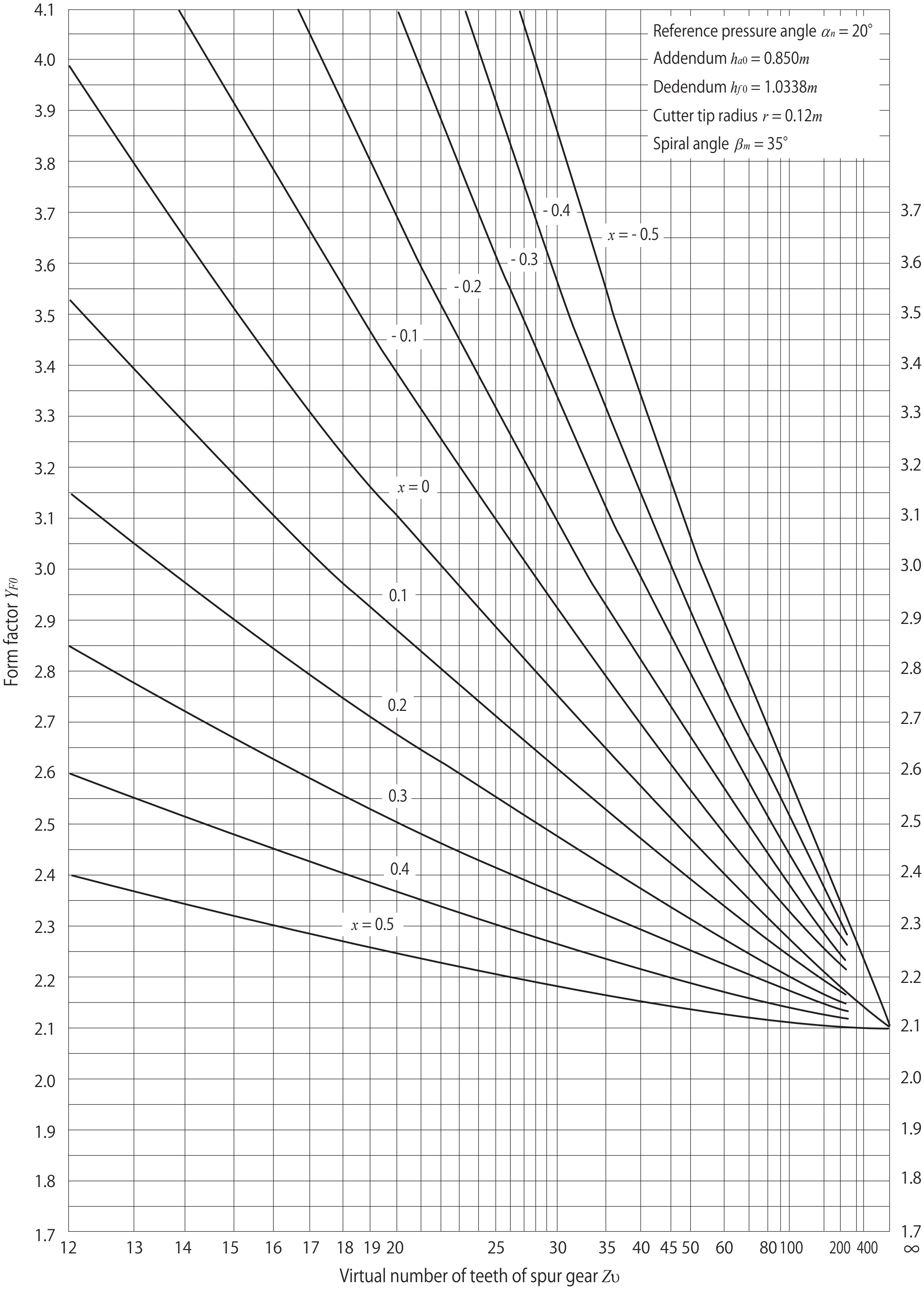
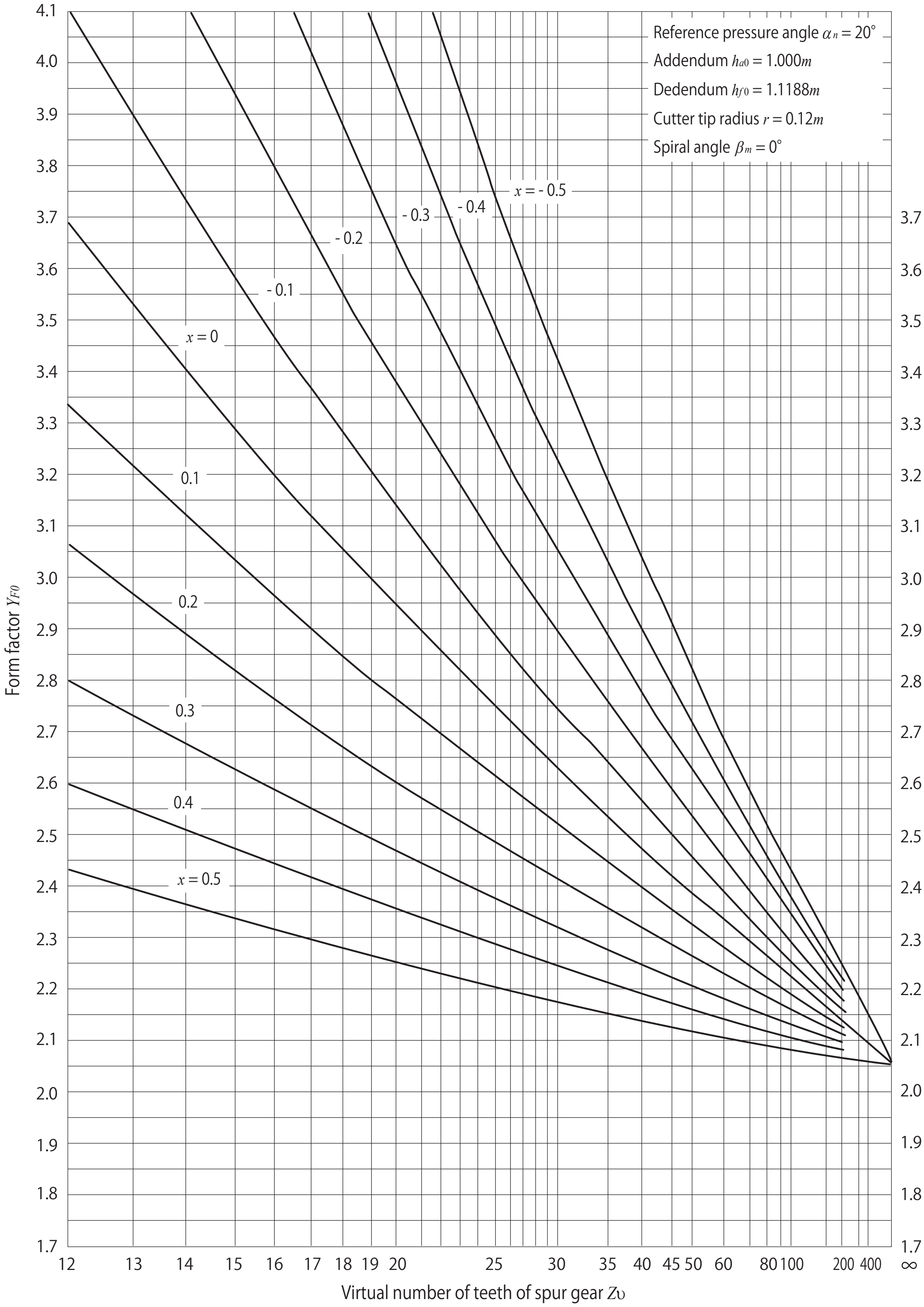


Fig. 3 Form factor graph (No.5)



5.1.3 Load distribution factor Y_ε

Calculation of Load distribution factor is as follows.

$$Y_\varepsilon = \frac{1}{\varepsilon_\alpha} \quad \cdots\cdots (20)$$

Hereby

ε_α : Transverse contact ratio

(a) Obtain Transverse contact ratio using following formula (21-24). However use Straight bevel gear's calculation formula for Zerol Bevel gear.

Straight bevel gear

$$\varepsilon_\alpha = \frac{\sqrt{R_{ra1}^2 - R_{rb2}^2} + \sqrt{R_{ra2}^2 - R_{rb2}^2} - (R_{r1} + R_{r2})\sin\alpha}{m\pi\cos\alpha} \quad \cdots\cdots (21)$$

Use following summarized calculation formula (1) for gear ratio $u \geqq 2$

$$\varepsilon_\alpha = \frac{\sqrt{R_{ra1}^2 - R_{rb1}^2} + h_{a2}\mathrm{cosec}\alpha - R_{r1}\sin\alpha}{m\pi\cos\alpha} \quad \cdots\cdots (22)$$

Spiral bevel gear

$$\varepsilon_\alpha = \frac{\sqrt{R_{ra1}^2 - R_{rb1}^2} + \sqrt{R_{ra2}^2 - R_{rb2}^2} - (R_{r1} + R_{r2})\sin\alpha_t}{m\pi\cos\alpha_t} \quad \cdots\cdots (23)$$

Use following summarized calculation formula (1) for gear ratio $\upsilon \geqq 2$

$$\varepsilon_\alpha = \frac{\sqrt{R_{ra1}^2 - R_{rb1}^2} + h_{a2}\mathrm{cosec}\alpha_t - R_{r1}\sin\alpha_t}{m\pi\cos\alpha_t} \quad \cdots\cdots (24)$$

Note (1) Formulas (21) and (23) becomes complicated for Gear section thus Gear is assumed as Rack to show a summarized formula as follows.

Hereby (refer to Fig. 4)

$R_{\upsilon a}$: Tip diameter (mm) for Virtual spur gear on the Back cone $= R_\upsilon + h_a = \gamma\sec\delta + h_a$

$R_{\upsilon b}$: Base radius (mm) for Virtual spur gear on the Back cone

For Straight bevel gear $= R_{\upsilon\cos\alpha} = \gamma\sec\delta\cos\alpha$

For Spiral bevel gear $= R_{\upsilon\cos\alpha t} = \gamma\sec\delta\cos\alpha_t$

R_υ : Back cone distance (mm) $= \gamma\sec\delta$

γ : Radius of pitch circle (mm) $= 0.5\, zm$

h_a : Outer addendum (mm)

α : Reference pressure angle (°)

α_t : Mean transverse pressure angle (°)

$= \tan^{-1}(\tan\alpha_n / \cos\beta_m)$

α_n : Normal reference pressure angle (°)

β_m : Mean spiral angle (°)

δ : Pitch angle (°)

m : Outer transverse module (mm)

z : Number of teeth

Subscript

1 : Pinion

2 : Gear

(b) Refer to Fig. 5 to calculate Transverse contact ratio ε_α for Straight bevel gear with Reference pressure angle 20° or Spiral bevel gear with Normal pressure angle 20°. Use formula (16) to calculate Virtual number of teeth of spur gear Z_υ and the following formula for u.

Straight bevel gear : $u = \dfrac{h_a}{m}$ ············ (25)

Spiral bevel gear : $u = \dfrac{h_a}{m\cos\beta_m}$ ············ (26)

Hereby

h_a : Outer addendum (mm)

m : Outer transverse module (mm)

βm : Mean spiral angle (°)

From Fig. 5, calculate Transverse contact ratio ε_α using following formulas.

Straight bevel gear : $\varepsilon_\alpha = \varepsilon_1 + \varepsilon_2$

Spiral bevel gear : $\varepsilon_\alpha = K\varepsilon'_\alpha$

$\varepsilon'_\alpha = \varepsilon_1 + \varepsilon_2$

Hereby

ε_α : Transverse contact ratio for Straight bevel gear

ε'_α : Virtual spur gear transverse contact ratio for Spiral bevel gear

$\varepsilon_1, \varepsilon_2$: Obtain Virtual spur gear contact ratio from Pitch point to Tooth tip for pinion and gear from Fig. 5

k : Use Table 2 conversion factor for Virtual spur gear normal contact ratio to Transverse contact ratio for Spiral bevel gear.

$= \cos^2\alpha_n\,(\cos^2\beta_m + \tan^2\alpha_n)$

α_n : Normal reference pressure angle (°)

β_m : Mean spiral angle (°)

Fig. 4 Engagement of Virtual spur gear on the Back cone

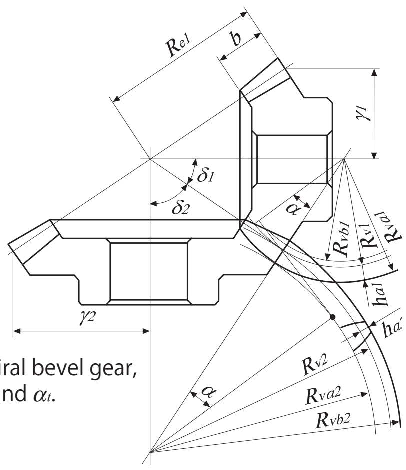
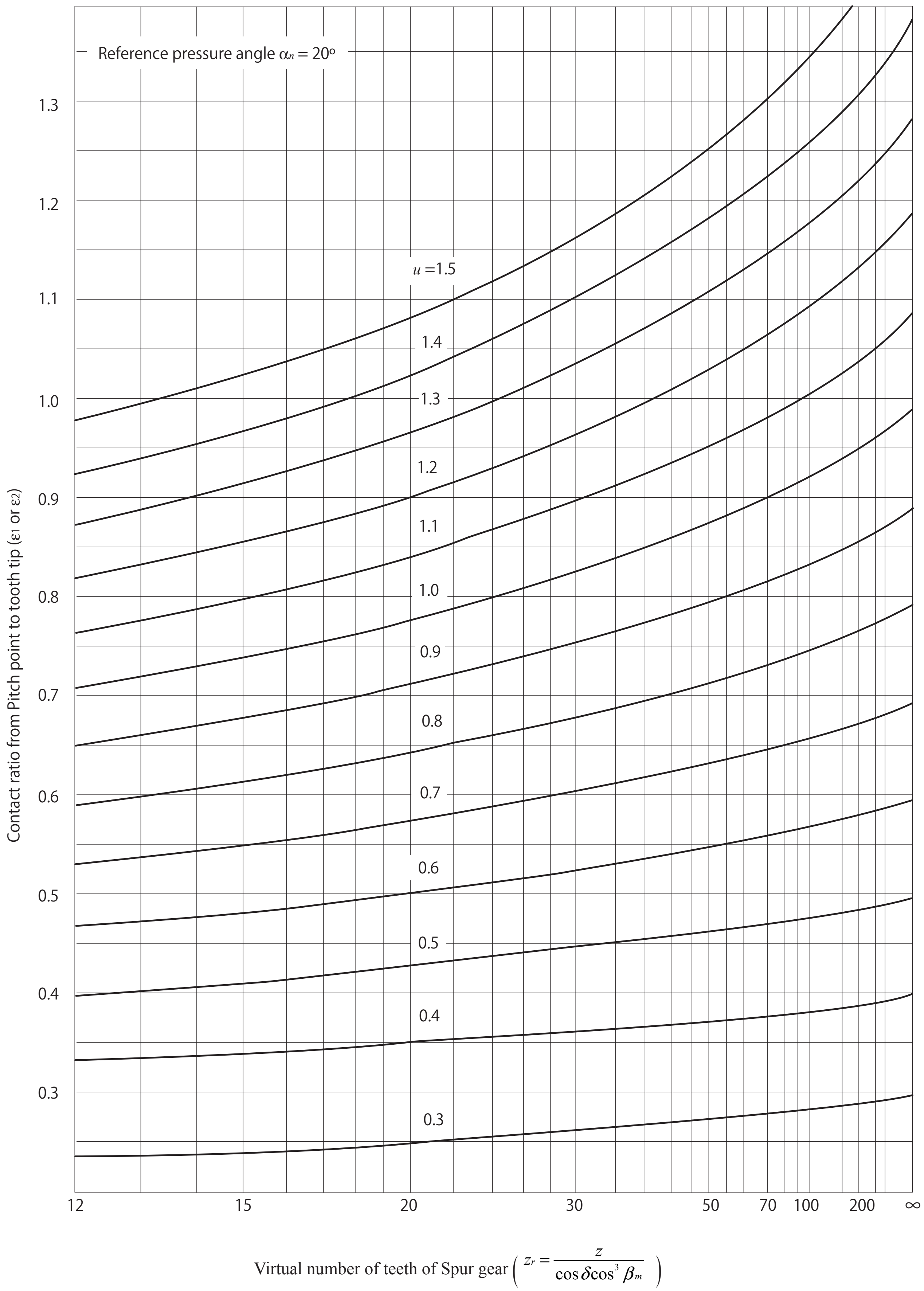


Table 2. Value of Conversion factor for Transverse contact ratio for Spiral bevel gear

Mean spiral angle βm / Normal Reference pressure angle αn	15°	20°	25°	30°	35°
20°	0.94085	0.89671	0.84229	0.77924	0.70949

Fig. 5 Table to obtain Contact ratio



5.1.4 Spiral angle factor Y_β

Calculate Spiral angle factor using following formulas. (Refer to Table 3 and Fig. 6)

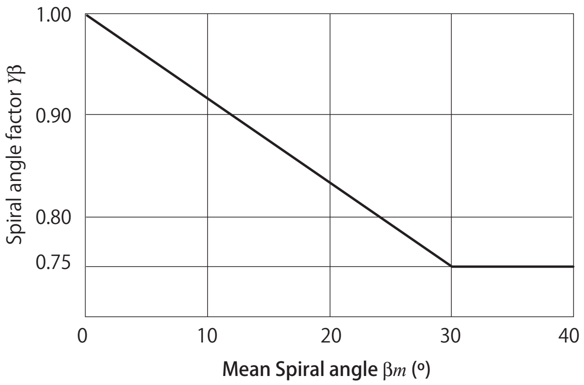
For $0° \leqq \beta_m \leqq 30°$: $Y_\beta = 1 - \frac{\beta_m}{120}$ .... (27)

For $\beta_m \geqq 30°$: $Y_\beta = 0.75$ .... (27)'

Table 3. Spiral angle factor

β_m	15°	20°	25°	30°	35°
Y_β	0.875	0.833	0.792	0.75	

Fig. 6 Spiral angle factor



5.1.5 Cutter diameter influence factor Y_C

Calculate Cutter diameter influence factor from Table 4 based on ratio cutter diameter for Length of tooth trace. If cutter diameter is unknown, Y_C=1.0. Length of tooth trace to be $b / \cos\beta_m$ (mm).

5.1.6 Life factor K_L

Refer to Table 2 of 5.1.5 under Spur gear.

5.1.7 Dimension factor for Tooth root factor K_{FX}

Obtain Dimension factor for Tooth root factor from transverse module in Table 5.

Table 5. Dimension factor for Tooth root factor K_{FX}

Outer transverse module m	Non surface hardening gear	Surface hardening gear
1.5< d ≦ 5	1.0	1.0
5 < d ≦ 7	0.99	0.98
7 < d ≦ 9	0.98	0.96
9 < d ≦ 11	0.97	0.94
11 < d ≦ 13	0.96	0.92
13 < d ≦ 15	0.94	0.90
15 < d ≦ 17	0.93	0.88
17 < d ≦ 19	0.92	0.86
19 < d ≦ 22	0.90	0.83
22 < d ≦ 25	0.88	0.80

5.1.8 Tooth distributed factor for Tooth load K_M

Calculate load distribution factor for Tooth trace from Tables 6 and 7.

5.1.9 Dynamic load factor K_V

Using Gear accuracy and Circumferential speed on the Outer pitch circle from Table 8 to obtain Dynamic factor.

5.1.10 Overload factor K_O

Refer to formula (23) and Table 4 of 5.1.8 under Spur gear.

Table 4. Cutter diameter influence factor Y_C

Types	Cutter diameter			
	∞	6 times Length of tooth trace	5 times Length of tooth trace	4 times Length of tooth trace
Straight bevel gear	1.15	-	-	-
Spiral bevel gear Zerol Bevel gear	-	1.00	0.95	0.90

Table 6. Tooth trace load distribution factor K_M for Spiral bevel, Zerol bevel and Straight bevel gears (Crowning)

		Full support to both gears	Support to one side of gear	Support to both gears on one side
Stiffness of axis and gearbox	Especially strong	1.2	1.35	1.5
	Normal	1.4	1.6	1.8
	Weak	1.55	1.75	2.0

Table 7. Tooth trace load distributed factor K_M for Straight bevel gear without Crowning

		Full support to both gears	Support to one side of gear	Support to both gears on one side
Stiffness of axis and gearbox	Especially strong	1.05	1.15	1.35
	Normal	1.6	1.8	2.1
	Weak	2.2	2.5	2.8

Table 8. Dynamic factor K_V

System of accuracy from JIS B1704	Circumferential velocity (m/s)						
	Below 1	$1 < \upsilon \leqq 3$	$3 < \upsilon \leqq 5$	$5 < \upsilon \leqq 8$	$8 < \upsilon \leqq 12$	$12 < \upsilon \leqq 18$	$18 < \upsilon \leqq 25$
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	-	-	-	-	-

5.1.11 Reliability factor K_R

Reliability factor is as follows

(1) General cases $K_R = 1.2$

(2) Special cases

If clearly understood the usage conditions of impact from prime mover, driver side, stiffness of gearbox and axis for calculating Tooth bending strength. When determining numerical values of K_M, K_L, K_0 using .... $K_R = 1.0$.

In situations opposite from above where numerical values of K_0 and K_M are uncertain (use K_L as 1.0 in this case). .... $K_R = 1.4$

5.1.12 Allowable tooth root bending stress $\sigma_{F\lim}$

Refer to Tables 9, 10 and 13 of 5.1.10 under Spur gear.

5.2 How to calculate factors from calculation formula for Surface durability.

The following stipulates types of factor from calculation formula of Surface durability in previous paragraph.

5.2.1 Facewidth b (mm)

Facewidth b is stipulated to the Facewidth on Pitch cone. For different Facewidth between Pinion and Gear, select the narrower Effective facewidth.

5.2.2 Domain zone Z_H

Calculation of Domain zone is as follows.

$$Z_H = \sqrt{\frac{2\cos\beta_b}{\sin\alpha_t\cos\alpha_t}} \quad \cdots\cdots (28)$$

Hereby

β_b : $\tan^{-1}(\tan\beta_m \cos\alpha_t)$

α_t : Mean transverse pressure angle (°)

α_n : Normal reference pressure angle (°)

β_m : Mean spiral angle (°)

Obtain domain factor from Fig. 7 with Normal reference pressure angle 20°, 22.5°and 25°.

5.2.3 Elasticity factor Z_M

Refer to Table 6 of 5.2.3 under Spur gear

5.2.4 Contact ratio factor Z_ε

Obtain Contact ratio factor using following formula. Refer to Fig. 4 of 5.2.4 under Spur gear.

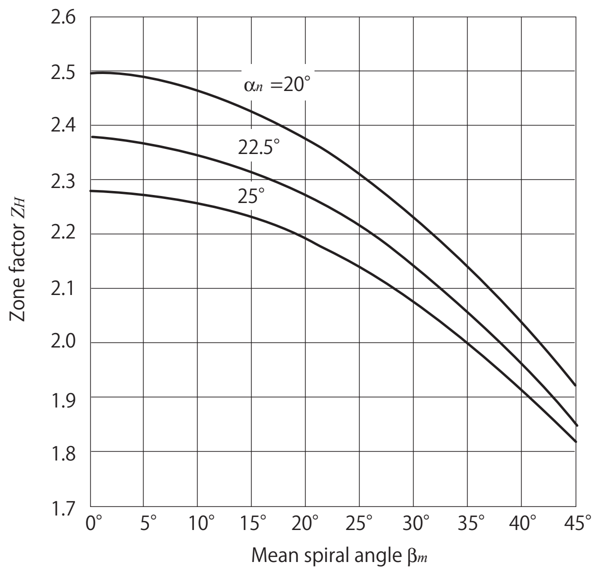
Straight bevel gear : $Z_\varepsilon = 1.0$ .... (29)

Spiral bevel gear :

In case of $\varepsilon_\beta \leqq 1$, $\quad Z_\varepsilon = \sqrt{1 - \varepsilon_\beta + \frac{\varepsilon_\beta}{\varepsilon_\alpha}}$ .... (30)

In case of $\varepsilon_\beta > 1$, $\quad Z_\varepsilon = \sqrt{\frac{1}{\varepsilon_\alpha}}$ .... (31)

Fig. 7 Zone factor



Hereby

ε_α : Transverse contact ratio

ε_β : Overlap ratio

Calculate Transverse contact ratio from 5.1.3 (a) under Bevel gear.

Overlap ratio is defined below

$$\varepsilon_\beta = \frac{R_e}{R_e - 0.5b}\,\frac{b\tan\beta_m}{\pi m} \quad \cdots\cdots (32)$$

Hereby

R_e : Cone distance (mm)

b : Facewidth (mm)

β_m : Mean spiral angle (°)

m : Outer transverse module (mm)

5.2.5 Spiral angle factor for Surface durability Z_β

Spiral angle factor for Surface durability is difficult to stipulate accurately due to insufficient data. Calculation formula is $Z_\beta = 1.0$ .... (33)

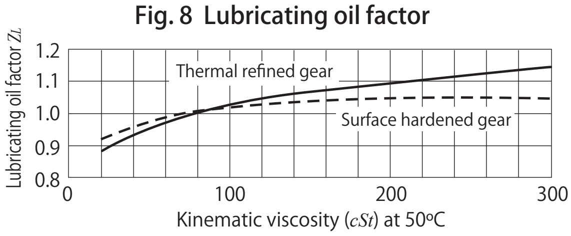
5.2.6 Life factor for Surface durability K_{HL}

Refer to Table 7 of 5.2.6 under Spur gear.

5.2.7 Lubricating oil factor Z_L

For the 2 types of gear stated below, obtain Lubricating oil factor from Fig.8 based on Kinematic viscosity (cSt) at 50°C.

Fig. 8 Lubricating oil factor



(1) Thermal refined gear [1]: Use solid line in Fig. 8.

(2) Surface hardened gear: Use broken line in Fig. 8.

Note (1) Thermal refined gear includes gear with quenching, tempering and normalizing.

Remark: Casting steel gear is equivalent to thermal refined gear.

5.2.8 Roughness factor Z_R

For 2 types of gear stated below, obtain average of maximum height of profile factor from Fig. 9 based on mean roughness of flank R_{maxm}(μm). Use the following formula to obtain the average of maximum height of profile roughness of flank R_{maxm} from R_{max1}, R_{max2}. (Meaning of R_{max1}, R_{max2} is Maximum height if profile roughness of flank inclusive of the effects of warm up and test run.)

$$R_{maxm} = \frac{R_{max1} + R_{max2}}{2} \sqrt[3]{\frac{100}{a}} (\mu m) \quad (34)$$

Hereby

$a = R_m (\sin\delta_1 + \cos\delta_1)$

R_m : Mean cone distance (mm)

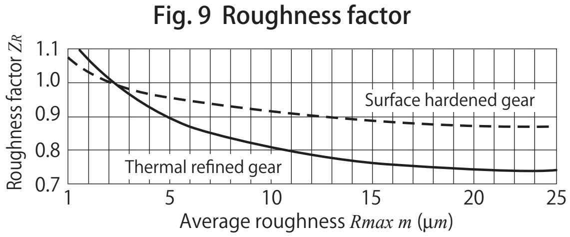
δ_1 : Pitch angle (°) of Pinion

(1) Thermal refined gear [1]: Use solid line in Fig. 9.

(2) Surface hardened gear: Use broken line in Fig. 9.

Refer to 5.2.7 for Note (1) and Remark

Fig. 9 Roughness factor



5.2.9 Lubricating speed factor Z_V

For the 2 types of gear stated below, obtain Lubricating velocity factor from Fig. 10 based on Circumferential velocity υ(m/s) on the Outer pitch circle.

(1) Thermal refined gear (1): Use solid line in Fig. 10.

(2) Surface hardened gear: Use broken line in Fig. 10.

Refer to 5.2.7 for Note (1) and Remark

Fig. 10 Lubricating speed factor

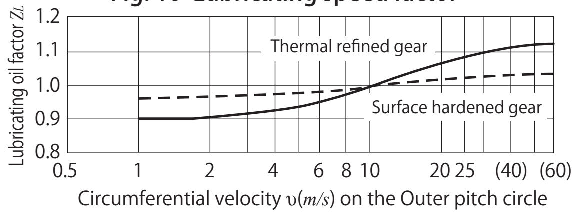


Table 11. Nitriding gear [1]

Material		Flank hardness (reference)	σ_{Hlim} kgf/mm²	
Nitriding steel	SACM 645 and others	Above HV 650	Normal	120
			Sustained period of Nitriding treatment	130 - 140

Note (1) Applicable to Gear with proper Nitriding depth and hardened surface to improve Surface durability. When Surface hardness is remarkably lower than above table. Starting point of maximum shear-stress force at inner gear tooth is remarkably deeper than depth of Nitriding, take note of providing a larger safety factor than usual.

Table 12. Nitrocarburizing gear [1]

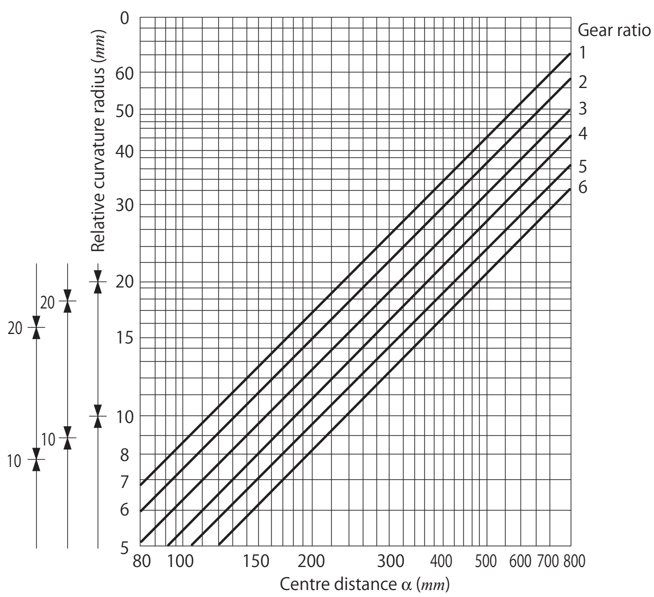
Material	Nitriding period (h)	σ_{Hlim} kgf/mm²		
		Relative curvature radius (mm) [2]		
		Below 10	10 - 20	Above 20
Carbon steel and Alloy steel for structural use	2	100	90	80
	4	110	100	90
	6	120	110	100

Note (1) Applicable to Salt bath and Gas Nitro-carburizing gears.

(2) Use Fig. 11 to obtain Relative curvature radius

Remark. Use properly adjusted material for core.

Fig. 11 Relative curvature radius



5.2.10 Hardness ratio factor Z_W

Refer to formula (35) and Table 8 from 5.2.10 under Spur gear.

5.2.11 Diameter factor K_{HX} for Surface durability

If Tooth profile and gear size increases, Surface durability also increases but has a tendency to increase disproportionately. Due to insufficient data at the moment, Dimension factor $K_{HX} = 1.0$ ························ (35)

5.2.12 Tooth trace load distribution factor $K_{H\beta}$ for Surface durability

Obtain Tooth trace load distribution factor for Surface durability from Tables 9 and 10. If both gears are without surface hardening, use 90% of values from Tables 9 and 10.

Table 9. Tooth trace load distribution factor $K_{H\beta}$ for Spiral Bevel, Zerol Bevel and Straight bevel gears (including Crowning)

Stiffness of axis and gearbox	Condition for gear support		
	Full support to both gears	Support to one side of gear	Support to both gears on one side
Especially strong	1.3	1.5	1.7
Normal	1.6	1.85	2.1
Weak	1.75	2.1	2.5

Table 10. Tooth trace load distribution factor $K_{H\beta}$ for Straight bevel gear without Crowning.

Stiffness of axis and gearbox	Condition for gear support		
	Full support to both gears	Support to one side of gear	Support to both gears on one side
Especially strong	1.3	1.5	1.7
Normal	1.85	2.1	2.6
Weak	2.8	3.3	3.8

5.2.13 Dynamic factor K_V

Refer to Table 8 from 5.1.9 under Bevel gear.

5.2.14 Overload factor K_o

Refer to formula (23) and Table 4 of 5.1.8 under Spur gear.

5.2.15 Reliability factor CR

Reliability factor for Surface durability is above 1.15.

5.2.16 Allowable hertz stress $\sigma_{H\lim}$

Refer to Tables 9 ~ 12 for Allowable hertz stress. For values not listed, use interpolation. Meaning of flank's hardness is hardness near Pitch circle.