Chapter 10 Calculation for Gear strength

10.1 Calculation of strength for Spur and Helical gears

There are calculations for Tooth bending strength (hereby called Bending strength), Surface durability and Scoring when considering gear strength. These are from ISO, JGMA, AGMA, DIN, BS and JSME.
KG had developed and marketed KG-CALMET for easy searching of suitable KG STOCK GEARS by entering gear data, tooth strength (Bending strength and Surface durability), profile generation, condition of engagement, Number of teeth and transfer torque.
Now to introduce the selected calculation formula for Bending strength and Surface durability from formula extracted from JGMA (Japan Gear Manufacture Association Standard) as follows.

Calculation formula of Bending strength for Spur and Helical gears JGMA 401-01 (1974).
Calculation formula of Surface durability for Spur and Helical gears JGMA 402-01 (1975).

1. Application range (common)

1.1 This standard is applied to Spur, Helical, Double helical and Internal gears that uses general industrial machinery transfer power.

Module	: 1.5 to 25.0 mm
Reference pitch diameter	: 25 to 3,200 mm
Circumferential velocity	: Below 25m/s
Revolving velocity	: Below 3,600 m^{-1}

Tooth profile of Spur and normal type of Helical gears as stipulated in JIS B 1701 (Involute tooth profile and dimensions). Also applicable to gears with Normal reference pressure angle of 22.5°and 25°

Accuracy	: Accuracy classes 1 to 6 stipulated in JIS B 1702 (Accuracy for Spur and Helical gear).

1.2.1 This standard stipulates calculation for Bending allowable load and when determining designated dimension based on Tooth root bending stress.

1.2.2 This standard stipulates calculation for Tooth surface allowable load for a gear with designated dimension and for calculating specifications based on flank stress.

2 Definition

2.1 Bending strength

Bending allowable load for gear is Allowable tangential load on the Reference pitch circle based on Allowable tooth root bending stress of gears when transferring power during operation.

2.2 Surface durability

Surface durability is stipulated as capacity of load it can withstand and still provide necessary strength and enough safety for gear against progressive pitting. Therefore, meaning of Allowable flank load is Allowable tangential load on the Reference pitch circle determined in accordance to Surface durability of its gears when transferring power during operations.

3. Basic formula (common)

In regards to calculating Gear strength, the conversion formulas related to calculating Tangential load on Reference pitch circle, Nominal power and Nominal torque are as follows.

3.1 Nominal tangential load on Reference pitch circle F_t(kgf)

$$F_t = \frac{102P}{v} = \frac{1.95\times10^6 P}{dn} \quad \cdots\cdots (1)$$

Hereby

P : Nominal power (kW)
v : Circumferential velocity (m/s) on the Reference pitch circle
d : Reference pitch diameter (mm)
n : Revolving velocity (min^{-1})

$$v = \frac{dn}{19100} \quad \cdots\cdots (2)$$

Or

$$F_t = \frac{2000T}{d} \quad \cdots\cdots (3)$$

Hereby

T : Nominal torque (kgf・m)

3.2 Nominal power (kW)

$$P = \frac{F_t v}{102} = \frac{10^{-6}}{1.95} F_t dn \quad \cdots\cdots (4)$$

3.3 Nominal torque (kgf・m)

$$T = \frac{F_t d}{2000} \quad \cdots\cdots (5)$$

Or

$$T = \frac{974P}{n} \quad \cdots\cdots (6)$$

4. Calculation formula for Strength

4.1 Bending strength

Nominal tangential load on the Reference pitch circle is necessary as reference for calculating Bending strength. Therefore, Nominal tangential load on the Reference pitch circle should be equal or below Allowable tangential load on the Reference pitch circle, which is derived from calculating Allowable tooth root bending stress. Therefore,

$$F_t \leqq F_{t\lim} \quad \cdots\cdots (7)$$

Hereby

F_t : Nominal tangential load on the Reference pitch circle (kgf)

$F_{t\lim}$: Calculate Allowable tangential load (kgf) on the Reference pitch circle by selecting the smaller value from either pinion or gear.

On the other hand, Tooth root stress calculated from Nominal tangential load on the Reference pitch circle should be equal or below Allowable tooth root bending stress.

Therefore

$$\sigma_F \leqq \sigma_{F\lim} \quad \cdots\cdots (8)$$

Hereby

σ_F : Dedendum stress calculated from Nominal tangential load on Reference pitch circle (kgf/mm²)

$\sigma_{F\lim}$: Allowable tooth root bending stress (kgf/mm²)

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

$$F_{t\lim} = \sigma_{F\lim} \frac{m_n b}{Y_F Y_\varepsilon Y_\beta} \left(\frac{K_L K_{FX}}{K_V K_O} \right) \frac{1}{S_F} \quad \cdots\cdots (9)$$

Hereby

m_n : Normal module (mm)

b : Facewidth (mm)

Y_F : Form factor

Y_ε : Load distribution factor

Y_β : Helix angle factor

K_L : Life factor

K_{FX}: Dimension factor for Tooth root stress

K_v : Dynamic factor

K_O : Overload factor

S_F : Safety factor for Tooth root bending damage

4.1.2 Calculation for Tooth root bending stress is as follow.

$$\sigma_F = F_t \frac{Y_F Y_\varepsilon Y_\beta}{m_n b} \left(\frac{K_V K_O}{K_L K_{FX}} \right) S_F \quad \cdots\cdots (10)$$

4.2 Calculation for Surface durability

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

$$F_t \leqq F_{t\lim} \quad \cdots\cdots (11)$$

Hereby F_t : Nominal tangential load on the Reference pitch circle (kgf)

$F_{t\lim}$: Calculate Allowable tangential load (kgf) on the Reference pitch circle by selecting the smaller value (kgf) from either pinion or gear.

On the other hand, Hertz stress from Nominal tangential load on the Reference pitch circle should be equal or below Allowable hertz stress.

Therefore

$$\sigma_H \leqq \sigma_{H\lim} \quad \cdots\cdots (12)$$

Hereby

σ_H : Hertz stress calculated from Nominal tangential load on Reference pitch circle (kgf/mm²)

$\sigma_{H\lim}$: Allowable hertz stress ((kgf/mm²)

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

$$F_{t\lim} = \sigma_{H\lim}{}^2 d_1 b_H \frac{u}{u \pm 1} \left(\frac{K_{HL} Z_L Z_R Z_V Z_W Z_{HX}}{Z_H Z_M Z_\varepsilon Z_\beta} \right)^2 \times \frac{1}{K_{H\beta} K_V K_O} \frac{1}{S_H{}^2} \quad \cdots\cdots (13)$$

+/- : '+' indicate the engagement with both External gears. '-' for engagement with External and Internal gears.

Hereby

d_1 : Reference pitch diameter for pinion (mm)

b_H : Effective facewidth for Surface durability (mm)

u : Gear ratio

Z_H : Zone factor

Z_M : Elasticity factor

Z_ε : Contact ratio factor

Z_β : Helix angle factor

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

K_{HX}: Dimension factor for Surface durability

$K_{H\beta}$: Face load factor for Contact stress

K_V : Dynamic factor

K_O : Overload factor

S_H : Safety factor for Surface durability

4.2.2 Calculation for Hertz stress is as follows.

$$\sigma_H = \sqrt{\frac{F_t}{d_1 b_H} \frac{u \pm 1}{u}} \frac{Z_H Z_M Z_\varepsilon Z_\beta}{K_{HL} Z_L Z_R Z_V Z_W K_{HX}} \times \sqrt{K_{H\beta} K_V K_O}\, S_H \quad \cdots\cdots (14)$$

+/- : '+' indicate the engagement with both External gears. '-' for engagement with External and Internal gears.

5. Calculation formula for types of factor

5.1 How to obtain the types of factor using the calculation formula of Bending strength.

The following stipulates types of factor from calculation formula of Bending strength in previous paragraph.

5.1.1 Facewidth b

When Facewidths differs, assume wider Facewidth to be b_w and smaller Facewidth to be b_s. $b_w - b_s \leqq m_n$, use actual Facewidth for calculations.

When $b_w - b_s > m_n$, b_s is used in formula b_s + mn to calculation of Facewidth.

5.1.2 Form factor Y_F

Refer to Fig. 1 to find Form factor.

For Virtual number of teeth of spur gear for Helical gear, use following calculation formula.

$$z_v = \frac{z}{\cos^3\beta} \quad \cdots\cdots (15)$$

For Form factor for Tooth profile excluding Fig. 1 please refer to this original standard.

5.1.3 Load distribution factor Y_ε

Calculating Load distribution factor using following formula.

$$Y_\varepsilon = \frac{1}{\varepsilon_\alpha} \quad \cdots\cdots (16)$$

Hereby

ε_α : Transverse contact ratio

Calculation formulas of Transverse contact ratio are as follows,

Spur gear : $$\varepsilon_\alpha = \frac{\sqrt{r_{a1}^2 - r_{b1}^2} + \sqrt{r_{a2}^2 - r_{b2}^2} - a\sin\alpha_\omega}{m\pi\cos\alpha_0} \quad \cdots\cdots (17)$$

Helical gear : $$\varepsilon_\alpha = \frac{\sqrt{r_{a1}^2 - r_{b1}^2} + \sqrt{r_{a2}^2 - r_{b2}^2} - a\sin\alpha_{\omega t}}{m_t\pi\cos\alpha_t} \quad \cdots\cdots (18)$$

$$\cos^2\beta_b = 1 - \sin^2\beta \bullet \cos^2\alpha_n \quad \cdots\cdots (19)$$

Hereby

γ_a : Tip (Outside) radius (mm)

γ_b : Base radius (mm)

a : Centre distance (mm)

α_w : Working pressure angle (°)

α_{wt} : Transverse contact pressure angle (°)

α : Reference pressure angle (°)

α_n : Normal pressure angle (°)

α_t : Transverse reference pressure angle (°)

β : Reference pitch cylindrical helix angle (°)

β_b : Base cylinder helix angle (°)

Subscript

1 : Pinion

2 : Gear

Remark 1. Table 1 shows the Transverse contact ratio ε_α for Standard spur gear with Reference pressure angle 20°.

Remark 2. Use following formula to calculate approximate value of Y_ε for Helical gear.

$$\frac{\cos^2\beta_b}{\varepsilon_\alpha} = \frac{1}{\varepsilon_{\alpha n}} \quad \cdots\cdots (20)$$

However, obtain Transverse contact ratio $\varepsilon_{\alpha n}$ for Virtual spur gear from Table 1 by using Virtual number of teeth of spur gear z_{v1} and z_{v2}.

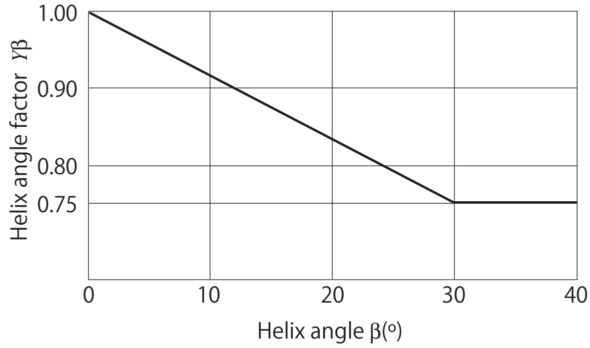
5.1.4 Helix angle factor Y_β

Calculate helix angle factor using following formula.

For $0° \leqq \beta \leqq 30°$: $Y_\beta = 1 - \dfrac{\beta}{120}$ $\cdots\cdots$ (21)

For $\beta \geqq 30°\beta$: $Y_\beta = 0.75$ $\cdots\cdots$ (22)

Fig. 2 Helix angle factor



5.1.5 Life factor K_L

Refer to Table 2 to obtain Life factor.

Table 2. Life factor K_L

Number of repeated	Hardness (1)(2) HB120 - 220	Hardness (2) Above HB221	Carburizing gear
Below 10,000	1.4	1.5	1.5
Approx. 100,000	1.2	1.4	1.5
Approx. 10^6	1.1	1.1	1.1
Above 10^7	1.0	1.0	1.0

Note (1) Steel casted gears to use this Table

Note (2) Core hardness is used for Induction hardened gear.

Meaning of repeated rotations is number of repeat during life span of gears. If uncertain, K_L =1.0.

Fig. 1 Graph for Form factor (Part 1 in Table 3)

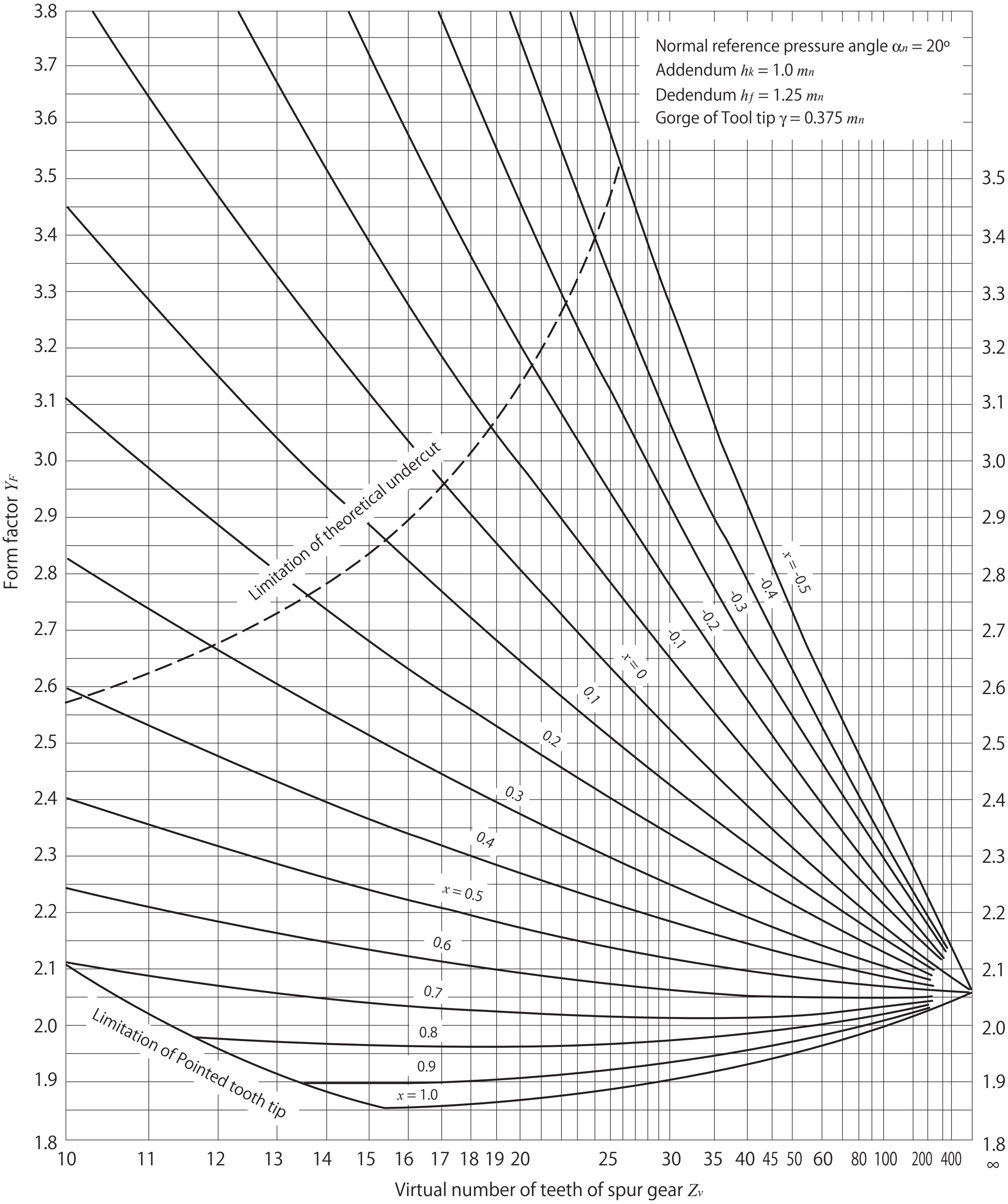
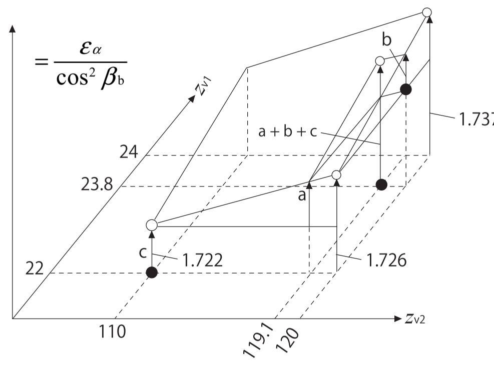


Table 1. Transverse contact ratio ε_α for Standard spur gear

	17	18	19	20	21	22	24	25	26	28	30	32	34	36	38	40	42	45	48	50	52	55	58	60	65	70	75	80	90	100	110	120	130	140	150	160	170	180	190	200
17	1.515																																							
18	1.522	1.529																																						
19	1.530	1.537	1.544																																					
20	1.536	1.543	1.550	1.557																																				
21	1.542	1.549	1.556	1.563	1.569																																			
22	1.548	1.555	1.562	1.569	1.575	1.581																																		
24	1.558	1.566	1.573	1.579	1.586	1.591	1.602																																	
25	1.563	1.571	1.578	1.584	1.590	1.596	1.607	1.612																																
26	1.568	1.575	1.582	1.589	1.595	1.601	1.611	1.616	1.621																															
28	1.576	1.584	1.591	1.597	1.604	1.609	1.620	1.625	1.629	1.638																														
30	1.584	1.592	1.599	1.605	1.611	1.617	1.628	1.633	1.637	1.646	1.654																													
32	1.591	1.599	1.606	1.612	1.618	1.624	1.635	1.640	1.644	1.653	1.661	1.668																												
34	1.598	1.605	1.612	1.619	1.625	1.631	1.641	1.646	1.651	1.659	1.667	1.674	1.681																											
36	1.604	1.611	1.618	1.625	1.631	1.637	1.647	1.652	1.657	1.665	1.673	1.680	1.687	1.692																										
38	1.609	1.617	1.624	1.630	1.636	1.642	1.653	1.658	1.662	1.671	1.678	1.686	1.692	1.698	1.703																									
40	1.614	1.622	1.629	1.635	1.641	1.647	1.658	1.663	1.667	1.676	1.684	1.691	1.697	1.703	1.708	1.714																								
42	1.619	1.626	1.633	1.640	1.646	1.652	1.662	1.667	1.672	1.680	1.688	1.695	1.702	1.708	1.713	1.718	1.723																							
45	1.625	1.633	1.640	1.646	1.652	1.658	1.669	1.674	1.678	1.687	1.695	1.702	1.708	1.714	1.720	1.725	1.729	1.736																						
48	1.631	1.639	1.646	1.652	1.658	1.664	1.675	1.680	1.684	1.693	1.701	1.708	1.714	1.720	1.725	1.731	1.735	1.742	1.748																					
50	1.635	1.642	1.649	1.656	1.662	1.668	1.678	1.683	1.688	1.696	1.704	1.711	1.718	1.724	1.729	1.734	1.739	1.745	1.751	1.755																				
52	1.638	1.646	1.653	1.659	1.665	1.671	1.682	1.687	1.691	1.700	1.707	1.715	1.721	1.727	1.732	1.737	1.742	1.749	1.754	1.758	1.761																			
55	1.643	1.650	1.657	1.664	1.670	1.676	1.686	1.691	1.696	1.704	1.712	1.719	1.726	1.732	1.737	1.742	1.747	1.753	1.759	1.763	1.766	1.771																		
58	1.647	1.655	1.662	1.668	1.674	1.680	1.691	1.696	1.700	1.709	1.716	1.724	1.730	1.736	1.741	1.746	1.751	1.758	1.763	1.767	1.770	1.775	1.779																	
60	1.650	1.657	1.664	1.671	1.677	1.683	1.693	1.698	1.703	1.711	1.719	1.726	1.733	1.739	1.744	1.749	1.754	1.760	1.766	1.770	1.773	1.778	1.782	1.785																
65	1.656	1.663	1.670	1.677	1.683	1.689	1.699	1.704	1.709	1.717	1.725	1.732	1.739	1.745	1.750	1.755	1.760	1.766	1.772	1.776	1.779	1.784	1.788	1.791	1.797															
70	1.661	1.669	1.676	1.682	1.688	1.694	1.705	1.710	1.714	1.723	1.731	1.738	1.744	1.750	1.756	1.761	1.765	1.772	1.778	1.781	1.785	1.789	1.794	1.796	1.802	1.808														
75	1.666	1.673	1.680	1.687	1.693	1.699	1.710	1.714	1.719	1.728	1.735	1.742	1.749	1.755	1.760	1.765	1.770	1.777	1.782	1.786	1.789	1.794	1.798	1.801	1.807	1.812	1.817													
80	1.670	1.678	1.685	1.691	1.697	1.703	1.714	1.719	1.723	1.732	1.740	1.747	1.753	1.759	1.765	1.770	1.774	1.781	1.787	1.790	1.794	1.798	1.803	1.805	1.811	1.817	1.821	1.826												
90	1.678	1.685	1.692	1.699	1.705	1.711	1.721	1.726	1.731	1.739	1.747	1.754	1.760	1.766	1.772	1.777	1.782	1.788	1.794	1.798	1.801	1.806	1.810	1.813	1.819	1.824	1.829	1.833	1.840											
100	1.684	1.691	1.698	1.705	1.711	1.717	1.727	1.732	1.737	1.745	1.753	1.760	1.767	1.773	1.778	1.783	1.788	1.794	1.800	1.804	1.807	1.812	1.816	1.819	1.825	1.830	1.835	1.839	1.846	1.853										
110	1.689	1.696	1.703	1.710	1.716	1.722	1.732	1.737	1.742	1.750	1.758	1.765	1.772	1.778	1.783	1.788	1.793	1.799	1.805	1.809	1.812	1.817	1.821	1.824	1.830	1.835	1.840	1.844	1.852	1.858	1.863									
120	1.693	1.701	1.708	1.714	1.720	1.726	1.737	1.742	1.746	1.755	1.762	1.770	1.776	1.782	1.787	1.792	1.797	1.804	1.809	1.813	1.816	1.821	1.825	1.828	1.834	1.840	1.844	1.849	1.856	1.862	1.867	1.871								
130	1.697	1.704	1.711	1.718	1.724	1.730	1.740	1.745	1.750	1.758	1.766	1.773	1.780	1.786	1.791	1.796	1.801	1.807	1.813	1.817	1.820	1.825	1.829	1.832	1.838	1.843	1.848	1.852	1.860	1.866	1.871	1.875	1.879							
140	1.700	1.708	1.715	1.721	1.727	1.733	1.744	1.749	1.753	1.762	1.769	1.777	1.783	1.789	1.794	1.799	1.804	1.811	1.816	1.820	1.823	1.828	1.832	1.835	1.841	1.847	1.851	1.856	1.863	1.869	1.874	1.878	1.882	1.885						
150	1.703	1.710	1.717	1.724	1.730	1.736	1.747	1.751	1.756	1.765	1.772	1.779	1.786	1.792	1.797	1.802	1.807	1.813	1.819	1.823	1.826	1.831	1.835	1.838	1.844	1.849	1.854	1.858	1.866	1.872	1.877	1.881	1.885	1.888	1.891					
160	1.706	1.713	1.720	1.727	1.733	1.738	1.749	1.754	1.759	1.767	1.775	1.782	1.788	1.794	1.800	1.805	1.810	1.816	1.822	1.825	1.829	1.834	1.838	1.840	1.847	1.852	1.857	1.861	1.868	1.874	1.879	1.884	1.888	1.891	1.894	1.896				
170	1.708	1.715	1.722	1.729	1.735	1.741	1.751	1.756	1.761	1.769	1.777	1.784	1.791	1.797	1.802	1.807	1.812	1.818	1.824	1.828	1.831	1.836	1.840	1.843	1.849	1.854	1.859	1.863	1.871	1.877	1.882	1.886	1.890	1.893	1.896	1.898	1.901			
180	1.710	1.717	1.724	1.731	1.737	1.743	1.753	1.758	1.763	1.771	1.779	1.786	1.793	1.799	1.804	1.809	1.814	1.820	1.826	1.830	1.833	1.838	1.842	1.845	1.851	1.856	1.861	1.865	1.873	1.879	1.884	1.888	1.892	1.895	1.898	1.901	1.903	1.905		
190	1.712	1.719	1.726	1.733	1.739	1.745	1.755	1.760	1.765	1.773	1.781	1.788	1.795	1.800	1.806	1.811	1.816	1.822	1.828	1.832	1.835	1.840	1.844	1.847	1.853	1.858	1.863	1.867	1.874	1.881	1.886	1.890	1.894	1.897	1.900	1.902	1.905	1.907	1.909	
200	1.713	1.721	1.728	1.734	1.741	1.746	1.757	1.762	1.766	1.775	1.783	1.790	1.796	1.802	1.808	1.813	1.817	1.824	1.830	1.833	1.837	1.841	1.846	1.848	1.854	1.860	1.865	1.869	1.876	1.882	1.887	1.892	1.895	1.899	1.902	1.904	1.906	1.908	1.910	1.912

$$\varepsilon_\alpha = \frac{\sqrt{r_{a1}^2 - r_{b1}^2} + \sqrt{r_{a2}^2 - r_{b2}^2} - a \bullet \sin\alpha_\omega}{m\pi\cos\alpha}$$

$$= \frac{\varepsilon_\alpha}{\cos^2\beta_b}$$



Calculation of transverse contact ratio for Helical gear

Example: Calculate $\varepsilon\alpha$ of Helical gear with $z_1 = 20, z_2 = 100, \beta = 19°22''$

Firstly calculate $Z_{v1} = 23.8$, $Z_{v2} = 119.1$ from formula (18), secondly calculate $\varepsilon\alpha = 1.722$ to compare between engagements of 22 and 110 where the difference is 0.004.
Obtain $\varepsilon\alpha = 1.726$ to compare between engagements of 22 and 120 where the difference is 0.004.
Obtain $\varepsilon\alpha = 1.737$ to compare between engagements of 24 and 120 where the difference is 0.011.

$$a = 0.004 \times \frac{119.1 - 110}{120 - 110} = 0.00364$$

$$b = 0.011 \times \frac{23.8 - 22}{24 - 22} = 0.0099$$

Transverse contact ratio $\varepsilon\alpha$ between $c = 22$ and 110 is 1.722

$$a + b + c = 1.73554$$

Calculate $\cos^2\beta b = 0.900286478$ from formula 21
Therefore,
$\varepsilon\alpha = 1.73554 \times 0.90286478 = 1.567$ (theoretical value is 1.568).

5.1.6 Dimension factor K_{FX} for Tooth root stress

With increased Tooth profile, Bending strength is influenced. At the moment, due to insufficient data Dimension factor will be 1.0.

5.1.7 Dynamic factor K_V

Obtain Dynamic factor from Table 3 using gear accuracy and Circumferential speed on the Reference pitch circle.

Table 3. Dynamic factor K_V

System of accuracy from JIS B 1702		Circumferential speed on the Reference pitch circle (m/s)						
Tooth profile		Below 1	Above 1.0 to below 3.0	Above 3.0 to below 5.0	Above 5.0 to below 8.0	Above 8.0 to below 12.0	Above 12.0 to below 18.0	Above 18.0 to below 25.0
Normal	Modified							
	1	-	-	1.0	1.0	1.1	1.2	1.3
1	2	-	1.0	1.05	1.1	1.2	1.3	1.5
2	3	1.0	1.1	1.15	1.2	1.3	1.5	-
3	4	1.0	1.2	1.3	1.4	1.5	-	-
4	-	1.0	1.3	1.4	1.5	-	-	-
5	-	1.1	1.4	1.5	-	-	-	-
6	-	1.2	1.5	-	-	-	-	-

5.1.8 Overload factor K_0

Obtain Overload factor using following formula.

$$K_O = \frac{\text{Actual tangential load}}{\text{Nominal tangential load } (F_t)} \quad \cdots\cdots\cdots (23)$$

Use Table 4 to obtain Actual tangential load if uncertain of value.

Table 4. Overload factor K_0

Impact from motor side	Impact from load		
	Flat load	Average impact	Heavy impact
Flat load (Electric, turbine, hydraulic motors)	1.0	1.25	1.75
Light impact (Multi cylinder engine)	1.25	1.5	2.0
Average impact(Single cylinder engine)	1.5	1.75	2.25

Note: If the impact from load is unknown, refer to Table 5.

5.1.9 Safety factor S_F for damage from Tooth root bending

Fixed value of Safety factor for damage from Tooth root bending is difficult to be determined due to various internal and external factors. Minimum factor of 1.2 is necessary.

5.1.10 Allowable Tooth root bending stress $\sigma_{F\lim}$

Refer to Tables 9 and 10 for Allowable tooth root bending stress for gear with fixed load direction. For intermediate Hardness values in the tables shown, it is our recommendation to use interpolation values. When load direction is bi-directional, value of Allowable tooth root bending stress $\sigma_{F\lim}$ will be 2/3 of values in the table. For exmple, an idler gear or gear which alternates bi-directionally and for equal loads on either right or left teeth.

Value of hardness or core hardness uses centre of Tooth root.

Table 5. Classification of load for Driven machine

Name of Driven machine	Range	Name of Driven machine	Range	Name of Driven machine	Range
Agitator	M	Elevator	U	Petroleum refinery machinery	M
Blower	U	Extruder	U	Paper mill machinery	M
Brewing and Distillation apparatus	U	Fan (electric fan)	U	Timber mill machinery	H
Vehicles	M	Fan (for industries)	M	Pump	M
Clarifier	U	Feeder	M	Rubber machinery (medium load)	M
Sorting Machine	M	Feeder (to and fro motion)	H	Rubber machinery (heavy load)	H
Ceramics industry machine (medium load)	M	Food machinery	M	Water treatment machine (light load)	U
Ceramics industry machine (heavy load)	H	Hammer mill	H	Water treatment machine (medium load)	M
Compressor	M	Hoist	M	Screen (fluid)	U
Conveyer (uniform load)	U	Machine tools (main drive)	M	Screen (gravel)	M
Conveyer (uniform load / heavy load)	M	Machine tools (supplementary drive)	U	Sugar plant machinery	M
Crane	U	Metalwork machinery	H	Textile machinery	M
Crusher	H	Rotary mill	M	Iron mill machinery (hot rolling)	H
Dredger (Medium load)	M	Tumbler	H	Iron mill machinery (cold rolling)	U
Dredger (heavy load)	H	Mixer	M		

Note U: Uniform load, M: Medium impact, H: Heavy impact

5.2 How to obtain each factor based on calculation for Surface durability

Factors using calculation formulas based on Surface durability as mentioned above is defined below.

5.2.1 Effective facewidth for Surface durability b_H (mm)

Obtain Effective facewidth for Surface durability from (a) and (b).

(a) For different Facewidth between pinion and gear, select the narrower Facewidth as Effective facewidth.

(b) For Facewidth with end relief at both ends, Effective facewidth is the narrower of the Facewidth deducted by such end relief areas.

5.2.2 Zone factor Z_H

Calculation of Zone factor is as follows.

$$Z_H = \sqrt{\frac{2\cos\beta_b \cos\alpha_{wt}}{\cos^2\alpha_t \sin\alpha_{wt}}} = \frac{1}{\cos\alpha_t}\sqrt{\frac{2\cos\beta_b}{\tan\alpha_{wt}}} \quad \cdots\cdots (24)$$

Hereby

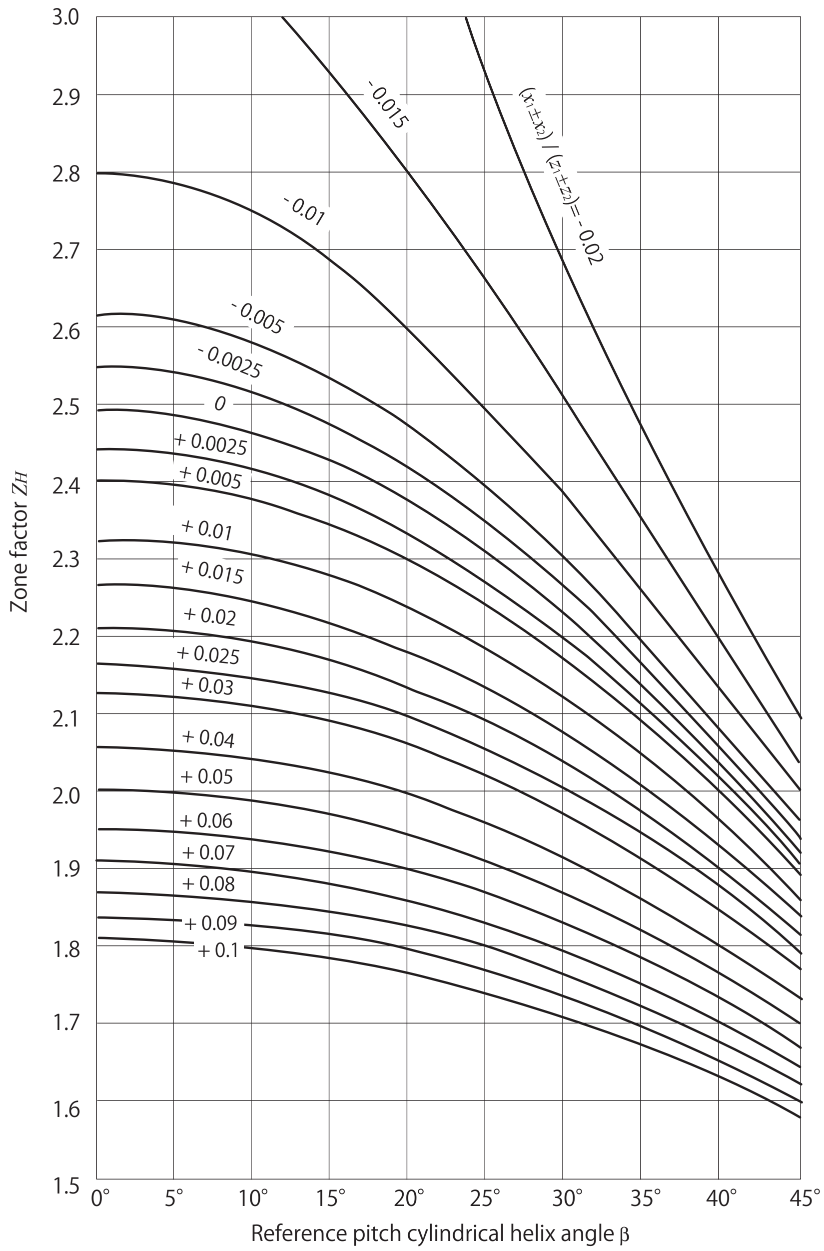
β_b : Base cylinder helix angle (°)

α_{wt} : Transverse contact pressure angle (°)

α_t : Transverse reference pressure angle (°)

(a) Obtain Zone factor from Fig. 3 with Normal reference pressure angle of 20° defined in JIS.

Fig. 3 Zone factor Z_H (Normal reference pressure angle $\alpha_n = 20°$)



In Fig. 3, x : Rack shift coefficient (Normal rack shift coefficient for Helical gear and Superscript) 1 is Pinion and 2 is Gear.)
z : Number of teeth
β : Reference pitch cylindrical helix angle (°)

(b) Factors from above formula and figure are defined as follows.

$$\beta_b = \tan^{-1}(\tan\beta\cos\alpha_t) \quad \cdots\cdots (25)$$

$$\mathrm{inv}\,\alpha_{wt} = 2\tan\alpha_n\left(\frac{x_1 \pm x_2}{z_1 \pm z_2}\right) + \mathrm{inv}\,\alpha_t \quad \cdots\cdots (26)$$

$$\alpha_t = \tan^{-1}(\tan\alpha_n / \cos\beta) \quad \cdots\cdots (27)$$

(c) Zone factor is based upon Curvature radius of flank at Pitch point. Therefore this factor is used for calculating Allowable load for flank. Due to Relative curvature radius at the worst load point is slightly smaller than that at Pitch point, such Zone factor cannot be use. These are Spur gear or Helical gear with extremely small Overlap ratio ($\varepsilon_\beta <$ about 0.5) with below minimum number of teeth ($z \leqq$ about 23) and small Rack shift coefficient. For such cases, please refer to 4.2.2 to check for Hertz stress at the worst load point.

5.2.3 Elasticity factor Z_M

Calculation of Elasticity factor is as follows.

$$Z_M = \sqrt{\frac{1}{\pi\left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right)}} \quad \cdots\cdots (28)$$

Hereby
ν : Poisson's ratio
E : Modulus of direct elasticity (Young's modulus) (kgf/mm^2)

For Z_M, refer to Table 6 for combinations of main gear materials.

5.2.4 Contact ratio factor Z_ε

Obtain Contact ratio factor using following formula (refer to Fig 4).

Spur gear : $Z_\varepsilon = 1.0 \quad \cdots\cdots (29)$

Fig. 4 Contact ratio factor

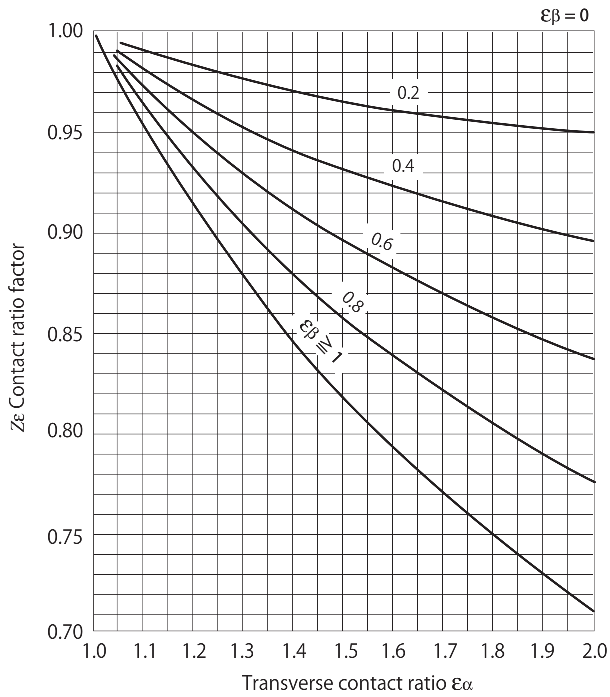


Table 6. Elasticity factor Z_M

Gear				Mating gear				Elasticity factor Z_M (kgf/mm^2)$^{0.5}$
Materials	Vocabularies	Modulus of direct elasticity E kgf/mm^2	Poisson's ratio ν	Materials	Vocabularies	Modulus of direct elasticity E kgf/mm^2	Poisson's ratio ν	
Structural steel	*(1)	21000	0.3	Structural steel	*(1)	21000	0.3	60.6
				Casting steel	SC	20500		60.2
				Spheroidal graphite iron	FCD	17600		57.9
				Gray iron casting	FC	12000		51.7
Casting steel	SC	20500		Casting steel	SC	20500		59.9
				Spheroidal graphite iron	FCD	17600		57.6
				Gray iron casting	FC	12000		51.5
Spheroidal graphite iron	FCD	17600		Spheroidal graphite iron	FCD	17600		55.5
				Gray iron	FC	12000		50.0
Gray iron casting	FC	12000		Gray iron casting	FC	12000		45.8

Note(1) *Structural steel to be S ~ C, SNC, SNCM, SCr, SCM.

Helical gear : in case $Z_\varepsilon = \sqrt{1-\varepsilon_\beta+\frac{\varepsilon_\beta}{\varepsilon_\alpha}}$ $\varepsilon_\beta \leqq 1$ .... (30)

: in case $Z_\varepsilon = \sqrt{\frac{1}{\varepsilon_\alpha}}$ $\varepsilon_\beta > 1$ .... (31)

Hereby

ε_α : Transverse contact ratio (refer to Clause 5.1.3 and Reference 1)

ε_β : Overlap ratio

5.2.5 Helix angle factor Z_β

Helix angle factor for Surface durability is difficult to accurately stipulate due to insufficient data. Calculation formula will be

$Z_\beta = 1.0$ .... (32)

5.2.6 Life factor for Surface durability K_{HL}

Obtain Life factor for Surface durability from Table 7

Table 7. Life factor of Surface durability

Number of repeated	Life factor for Surface durability
Below 10,000	1.5
About 100,000	1.3
About 10^6	1.15
Above 10^7	1.0

Remark 1. 'Repeated' is number of times of engaged rotation during life span.

Remark 2. Normally idler gear makes 2 engagements per rotation. However for engagements between different flanks for 1 rotation, it should be counted as 1 engagement.

Remark 3. For reversible rotation or similar conditions, number of rotation is from larger load applied to either flank.

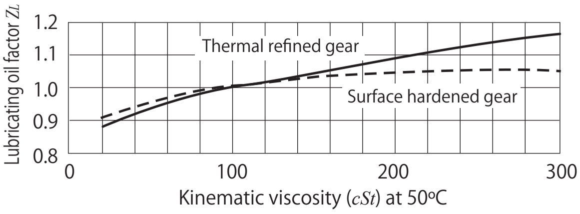
If number of times is uncountable, life factor to be

$K_{HL} = 1.0$ .... (33)

5.2.7 Lubricating oil factor Z_L

For the 2 types of gear stated below, obtain Lubricating oil factor from Fig. 5 based on Kinematic viscosity (cSt) at 50°C.

Fig. 5 Lubricating oil factor



(1) Thermal refined gear [(1)]: Use solid line in Fig. 5.

(2) Surface hardened gear: Use broken line in Fig. 5.

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

Find Roughness factor based on average roughness of flank $R_{maxm}(\mu m)$ from Fig. 6 for 2 types of gears. Use the following formula to obtain the average of maximum height of profile roughness of flank R_{maxm} from R_{max1}, R_{max2} and centre distance a(mm). (Meaning of R_{max1}, R_{max2} is Maximum height if profile roughness of flank inclusive of the effects of warm up and test run.)

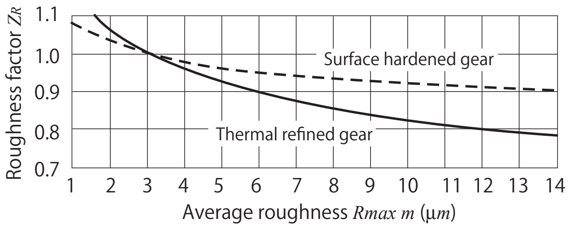
$$R_{maxm} = \frac{R_{max1}+R_{max2}}{2}\sqrt[3]{\frac{100}{a}}(\mu m) \quad \text{......................................} (34)$$

(1) Thermal refined gear [(1)]: Use solid line in Fig. 6.

(2) Surface hardened gear: Use broken line in Fig. 6.

Refer to 5.2.7 for Note (1) and Remark

Fig. 6 Roughness factor



5.2.9 Lubricating speed factor Z_V

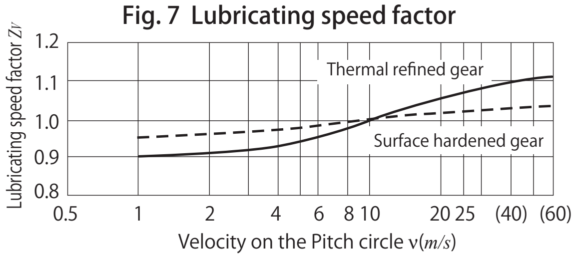
Find Lubricating speed factor based on maximum height of profile roughness of flank $R_{maxm}(\mu m)$ from Fig. 7 using either pinion or gears

(1) Thermal refined gear (1): Use solid line in Fig. 7.

(2) Surface hardened gear: Use broken line in Fig. 7.

Refer to 5.2.7 for Note (1) and Remark

Fig. 7 Lubricating speed factor



5.2.10 Work hardening factor Z_W

Hardness ratio factor is applied to engagement between gear and pinion(1) which is hardened ground. Calculation for Work hardening factor Z_w is as follow. (Refer to Fig. 8)

$$Z_W = 1.2 - \frac{HB_2 - 130}{1700} \quad \text{..} (35)$$

Hereby

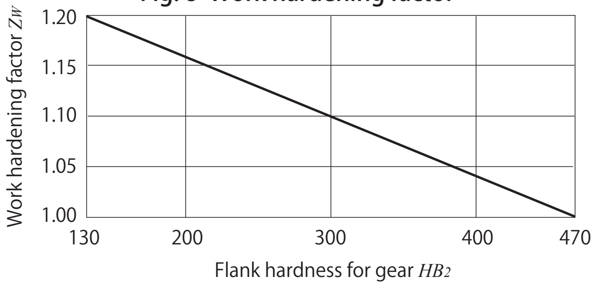
HB_2 : Hardness of gear flank (indicated by Brinell hardness)

However

Gear with conditions that cannot match above (35) and $130 \leqq HB_2 \leqq 470$, Pinion to be

$Z_W = 1.0$ .... (36)

Fig. 8 Work hardening factor



Note (1) Flank roughness of pinion is $R_{MAX1} \leqq 6\mu$m when engaged with stipulated gear.

5.2.11 Dimension 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

$$K_{HX} = 1.0 \quad (37)$$

5.2.12 Face load factor for contact stress $K_{H\beta}$

Obtain Face load factor for contact stress for Surface durability using following formula.

(a) If unable to estimate tooth contact conditions when load is applied to gear. Obtain Tooth trace load distribution factor from ratio (b/d_1) between Facewidth b and Reference diameter d_1 of pinion and from method of gear support from Table 8.

(b) Satisfactory tooth contact when load is applied to gear.

Tooth trace load distribution factor $K_{H\beta}$ for Surface durability depends on level of modification compared to used load (reference value). When calculating modifications on Tooth trace for following cases, analyse all causes that influence Tooth bearing when load is applied. Apply modifications of Proper Tooth trace for gear, Helix angle, Axial parallelism. Warm up and test run is performed and confirm Tooth bearing is secured during operation.

$$K_{H\beta} = 1.0 \sim 1.2 \quad (38)$$

5.2.13 Dynamic factor K_V (common)

Obtain Dynamic factor based on gear accuracy and Circumferential speed on the Reference pitch circle from 5.1.7 of Table 3.

5.2.14 Overload factor K_o (common)

Obtain the overload factor from 5.1.8 - Table 4.

5.2.15 Safety factor for flank damage (Pitting) S_H

A minimum Safety factor for flank damage (Pitting) value of 1.15 is necessary even though it is difficult to find fixed value of internal and external factors.

Table 8. Face load factor for contact stress

$\frac{b}{d_1}$	Supporting method			
	Support on both end			Unbalanced support
	Balanced to both bearings	Bearing is on one side and stiffness of axis is increased.	Bearing is on one side and less stiffness of axis.	
0.2	1.0	1.0	1.1	1.2
0.4	1.0	1.1	1.3	1.45
0.6	1.05	1.2	1.5	1.65
0.8	1.1	1.3	1.7	1.85
1.0	1.2	1.45	1.85	2.0
1.2	1.3	1.6	2.0	2.15
1.4	1.4	1.8	2.1	-
1.6	1.5	2.05	2.2	-
1.8	1.8	-	-	-
2.0	2.1	-	-	-

Remark 1. b is Effective facewidth for Spur and Helical gears. For Double helical gear, b is length of facewidth inclusive of cutter groove at centre of gear.

Remark 2. Tooth contact has to be satisfactory without load.

Remark 3. Inapplicable to Idler gear and pinion (Idler) engaged with gears.

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

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

Table 9. Gear without surface hardening

Materials (Arrow marks are for references only)		Hardness of flank HB	Hardness of flank HV	Lower limit of tensile strength kgf/mm² (reference)	σFlim kgf/mm²	σHlim kgf/mm²
Casting steel	SC37 SC42 SC46 SC49 SCC3			37	10.4	34
				42	12.0	35
				46	13.2	36
				49	14.2	37
				55	15.8	39
				60	17.2	40
Carbon steel for structural use with Normalizing		120	126	39	13.8	41.5
		130	136	42	14.8	42.5
		140	147	45	15.8	44
	S25C	150	157	48	16.5	45
		160	167	51	17.6	46.5
		170	178	55	18.4	47.5
	S35C	180	189	58	19.0	49
	S43C	190	200	61	19.5	50
	S48C	200	210	64	20	51.5
		210	221	68	20.5	52.5
	S53C	220	231	71	21	54
	S58C	230	242	74	21.5	55
		240	252	77	22	56.5
		250	263	81	22.5	57.5
Carbon steel for structural use with Quenching and Tempering		160	167	51	18.2	51
		170	178	55	19.4	52.5
		180	189	58	20.2	54
		190	200	61	21	55.5
		200	210	64	22	57
	S35C	210	221	68	23	58.5
		220	231	71	23.5	60
		230	242	74	24	61
		240	252	77	24.5	62,5
	S43C	250	263	81	25	64
	S48C	260	273	84	25.5	65.5
	S53C	270	284	87	26	67
	S58C	280	295	90	26	68.5
		290	305	93	26.5	70
		300	316	97		71
		310	327	100		72.5
		320	337	103		74
		330	347	106		75.5
		340	358	110		77
		350	369	113		78.5
Alloy steel for structural use with Carburizing, Quenching and Tempering		220	231	71	25	70
		230	242	74	26	71.5
		240	252	77	27.5	73
		250	263	81	28.5	74.5
		260	273	84	29.5	76
		270	284	87	31	77.5
	SMn443	280	295	90	32	79
		290	305	93	33	81
		300	316	97	34	82.5
	SNC836	310	327	100	35	84
	SCM435	320	337	103	36.5	85.5
	SCM440	330	347	106	37.5	87
		340	358	110	39	88.5
		350	369	113	40	90
	SNCM439	360	380	117	41	92
		370	391	121		93.5
		380	402	126		95
		390	413	130		96.5
		400	424	135		98

Table 9. Gear with High frequency induction hardening (continued)

Materials (Arrow marks are for references only)		Conditions of Heat treatment before High-frequency induction hardening	Core hardness HB	Core hardness HV	Flank hardness (1) HV	$\sigma_{F\lim}$ (2) kgf/mm²	$\sigma_{H\lim}$ kgf/mm²
Carbon steel for structural use	S48C S43C	Normalizing	160	167	Above 550	21	
			180	189	〃	21	
			220	231	〃	21.5	
			240	252	〃	22	
	S48C S43C	Induction hardening and Tempering	200	210	Above 550	23	
			210	221	〃	23.5	
			220	231	〃	24	
			230	242	〃	24.5	
			240	252	〃	25	
			250	263	〃	25	
Alloy steel for structural use	SMn443 SCM440 SNCM439 SCM435 SNC836	Induction hardening and tempering	230	242	Above 550	27	
			240	252	〃	28	
			250	263	〃	29	
			260	273	〃	30	
			270	284	〃	31	
			280	295	〃	32	
			290	305	〃	33	
			300	316	〃	34	
			310	327	〃	35	
			320	337	〃	36.5	
Carbon steel for structural use	S43C S48C	Normalizing			420		77
					440		80
					460		82
					480		85
					500		87
					520		90
					540		92
					560		93.5
					580		95
					Above 600		96
		Induction hardening and Tempering			500		96
					520		99
					540		101
					560		103
					580		105
					600		106.5
					620		107.5
					640		108.5
					660		109
					Above 680		109.5
Alloy steel for structural use	SMn443 SCM435 SCM440 SNC836 SNCM439	Induction hardening and Tempering			500		109
					520		112
					540		115
					560		117
					580		119
					600		121
					620		123
					640		124
					660		125
					Above 680		126

Note(1) When flank hardness is low, use $\sigma_{F\lim}$ value which is equivalent to gear without hardened surface.

Note(2) When gear has defects such as quenching cracks, insufficient hardening depth and uneven hardness, precaution is necessary as values of $\sigma_{F\lim}$ may become significantly lower compared with Tables 9 and 10. Values in Tables 9 and 10 are shown for full quenching at bottomland. Assuming insufficient quenching at bottomland, value will be 75% from Table 9 and 10.

Table 10. Gear with case hardening

Materials (Arrow marks are references only)		Effective carburizing depth [2]	Core hardness [1]		Flank hardness	$\sigma Flim$[2]	$\sigma Hlim$
			HB	HV	HV	kgf/mm²	kgf/mm²
Carbon steel for machine structural use	S15C S15CK		140	147		18.2	
			150	157		19.6	
			160	167		21	
			170	178		22	
			180	189		23	
			190	200		24	
		Relatively shallow depth (A)			580		115
					600		117
					620		118
					640		119
					660		120
					680		120
					700		120
					720		119
					740		118
					760		117
					780		115
					800		113
Alloy steel for machine structural use	SCM415 SCM415 SCM420 SNC815 SNCM420		220	231		34	
			230	242		36	
			240	252		38	
			250	263		39	
			260	273		41	
			270	284		42.5	
			280	295		44	
			290	305		45	
			300	316		46	
			310	327		47	
			320	337		48	
			330	347		49	
			340	358		50	
			350	369		51	
			360	380		51.5	
			370	390		52	
	SCM415(21) SCM420(22) SNC415(21) SNC815(22) SNCM420(23)	Relatively shallow depth (B)			580		131
					600		134
					620		137
					640		138
					660		138
					680		138
					700		138
					720		137
					740		136
					760		134
					780		132
					800		130
		Relatively deeper than above B			580		156
					600		160
					620		164
					640		166
					660		166
					680		166
					700		164
					720		161
					740		158
					760		154
					780		150
					800		146

Note (1) Relatively shallow effective case depth refers to below A and relatively deeper depth refers to B or more. Meaning of Effective case depth is hardness of up to HV513 (HRC50). Depth for Ground gear is after process.

Module		1.5	2	3	4	5	6	8	10	15	20	25
Effective depth	A	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.2	1.5	1.8
	B	0.3	0.3	0.5	0.7	0.8	0.9	1.1	1.4	2.0	2.5	3.4

Remark: Especially in engagement between gears, we recommend providing bigger Safety factor S_H., starting point of Maximum inner shear-stress force at inner gear tooth from surface pressure of flank is deeper than the depth of Case hardening which affects effectiveness of Carburizing depth.

Table 11. Nitriding gear [1]

Material		Flank hardness (reference)	σHlim 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 for improving Surface durability. We recommend providing a larger safety factor than usual when Surface hardness is lower than above table. Starting point of Maximum shear-stress force at inner gear tooth is deeper than depth of Nitriding.

Table 12. Nitro-carburizing [1]

Material	Nitriding period (h)	σHlim 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. 9 to obtain Relative curvature radius

Remark. Use properly adjusted gear material for core.

Table 13. Nitriding gear [1]

Material	Flank hardness (reference)	Core hardness		σFlim
		HB	HV	kgf/mm²
Alloy steel for structural use without Nitriding steel	Above HV650	220	231	30
		240	252	33
		260	273	36
		280	295	38
		300	316	40
		320	337	42
		340	358	44
		360	380	46
Nitriding steel SACM645	Above HV650	220	231	32
		240	252	35
		260	273	38
		280	295	41
		300	316	44

Note (1) Applicable to gear with proper Nitriding depth for improving Surface durability. However Nitriding layer is extremely thin from Nitro-carburizing, use $\sigma_{f\,\mathrm{lim}}$ value of the gear without hardened surface.

Fig. 9 Relative curvature radius