Table 17-26B Surface Strength Factor of Gleason Straight Bevel Gear

No.	Item	Symbol	Unit	Pinion	Gear
1	Allowable Hertz Stress	σ_{Hlim}	kgf/mm²	164	
2	Pinion's Pitch Diameter	d_1	mm	40.000	
3	Pinion's Pitch Cone Angle	δ_1	degree	26.56505º	
4	Cone Distance	R_e	mm	44.721	
5	Tooth Width	b		15	
6	Number of Teeth Ratio z_2/z_1	u		2	
7	Zone Factor	Z_H		2.495	
8	Material Factor	Z_M	(kgf/mm²)	60.6	
9	Contact Ratio	Z_ε		1.0	
10	Spiral Angle Factor	Z_β		1.0	
11	Life Factor	k_{HL}		1.0	
12	Lubricant Factor	Z_L		1.0	
13	Surface Roughness Factor	Z_R		0.90	
14	Sliding Speed Factor	Z_V		0.97	
15	Hardness Ratio Factor	Z_W		1.0	
16	Dimension Factor of Root Stress	k_{HX}		1.0	
17	Load Distribution Factor	$k_{H\beta}$		2.1	
18	Dynamic Load Factor	k_V		1.4	
19	Overload Factor	K_O		1.0	
20	Reliability Factor	C_R		1.15	
21	Allowable Tangential Force on Central Pitch Circle	F_{tlim}	kgf	103.0	103.0

17.5 Strength Of Worm Gearing

This information is applicable for worm gear drives that are used to transmit power in general industrial machines with the following parameters:

Axial Module:	m	1 to 25 mm
Pitch Diameter of Worm Gear:	d_2	less than 900mm
Sliding Speed:	v_5	less than 30m/sec
Rotating Speed, Worm Gear:	n_2	less than 600 rpm

17.5.1 Basic Formulas:

Sliding Speed, v_s (m/s)

$$V_s = \frac{d_1 n_1}{19100\cos\gamma} \qquad (17\text{-}48)$$

17.5.2 Torque, Tangential Force and Efficiency

(1) Worm as Driver Gear (Speed Reducing)

$$\left.\begin{aligned} T_2 &= \frac{F_t d_2}{2000} \\ T_1 &= \frac{T_2}{u\eta_R} = \frac{F_t d_2}{2000u\eta_R} \\ \eta_R &= \frac{\tan\gamma\left(1 - \tan\gamma\dfrac{\mu}{\cos\alpha_n}\right)}{\tan\gamma + \dfrac{\mu}{\cos\alpha_n}} \end{aligned}\right\} \quad \textbf{(17-49)}$$

where: T_2 = Nominal torque of worm gear (kgf.m)
T_1 = Nominal torque of worm (kgf.m)
F_t = Nominal tangential force on worm gear's pitch circle (kgf)
d_2 = Pitch diameter of worm gear (mm)
u = Teeth number ratio = z_2 / z_w
η_R= Transmission efficiency, worm driving (not including bearing loss, lubricant agitation loss, etc.)
μ = Friction coefficient

(2) Worm Gear as Driver Gear (Speed Increasing)

$$\left.\begin{aligned} T_2 &= \frac{F_t d_2}{2000} \\ T_1 &= \frac{T_2\eta_I}{u} = \frac{F_t d_2 \eta_I}{2000u} \\ \eta_I &= \frac{\tan\gamma - \dfrac{\mu}{\cos\alpha_n}}{\tan\gamma\left(1 + \tan\gamma\dfrac{\mu}{\cos\alpha_n}\right)} \end{aligned}\right\} \quad \textbf{(17-50)}$$

where: η_1 = Transmission efficiency, worm gear driving (not including bearing loss, lubricant agitation loss, etc.)

17.5.3 Friction Coefficient, μ

The friction factor varies as sliding speed changes. The combination of materials is important. For the case of a worm that is carburized and ground, and mated with a phosphorous bronze worm gear, see **Figure 17-12**. For some other materials, see **Table 17-27**.

For lack of data, friction coefficient of materials not listed in **Table 17-27** are very difficult to obtain. H.E. Merritt has offered some further information on this topic. See Reference 9.

Table 17-27 Combinations of Materials and Their Coefficient of Friction, μ

Combination of Materials	μ
Cast Iron and Phosphor Bronze	μ in Figure 17-12 times 1.15
Cast Iron and Cast Iron	μ in Figure 17-12 times 1.33
Quenched Steel and Aluminum Alloy	μ in Figure 17-12 times 1.33
Steel and Steel	μ in Figure 17-12 times 2.00

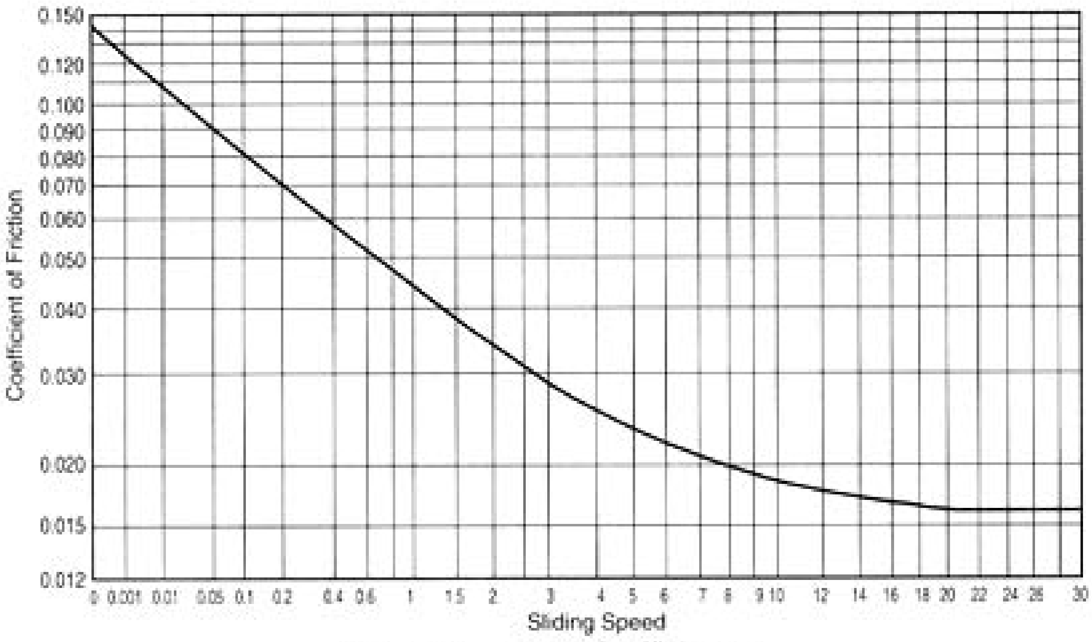

Fig. 17-12 Friction Coefficient, μ

17.5.4 Surface Strength of Worm Gearing Mesh

(1) Calculation of Basic Load

Provided dimensions and materials of the worm pair are known, the allowable load is as follows:

$$F_{t\,lim} = \text{Allowable tangential force (kgf)}$$
$$= 3.82 K_v K_n S_{clim} Z d_2^{0.8} m_x \frac{Z_L Z_M Z_R}{K_C} \qquad \textbf{(17-51)}$$

$$T_{2lim} = \text{Allowable worm gear torque (kgf}\cdot\text{m)}$$
$$= 0.00191 K_v K_n S_{clim} Z d_2^{1.8} m_x \frac{Z_L Z_M Z_R}{K_C} \qquad \textbf{(17-52)}$$

(2) Calculation of Equivalent Load

The basic load **Equations (17-51)** and **(17-52)** are applicable under the conditions of no impact and the pair can operate for 26000 hours minimum. The condition of "no impact" is defined as the starting torque which must be less than 200% of the rated torque; and the frequency of starting should be less than twice per hour.

An equivalent load is needed to compare with the basic load in order to determine an actual design load, when the conditions deviate from the above.

Equivalent load is then converted to an equivalent tangential force, F_{te}, in kgf:

$F_{te} = F_t K_h K_s$ (17-53)

and equivalent worm gear torque, T_{2e}, in kgf.m:

$T_{2e} = T_2 K_h K_S$ (17-54)

(3) Determination of Load

Under no impact condition, to have life expectancy of 26000 hours, the following relationships must be satisfied:

$F_t \le F_{tlim}$ or $T_2 \le T_{2lim}$ (17-55)

For all other conditions:

$F_{te} \le F_{tlim}$ or $T_{2e} \le T_{2lim}$ (17-56)

NOTE: If load is variable, the maximum load should be used as the criterion.

17.5.5 Determination of Factors in Worm Gear Surface Strength Equations

17.5.5.A Tooth Width of Worm Gear, b_2 (mm)

Tooth width of worm gear is defined as in **Figure 17-13**.

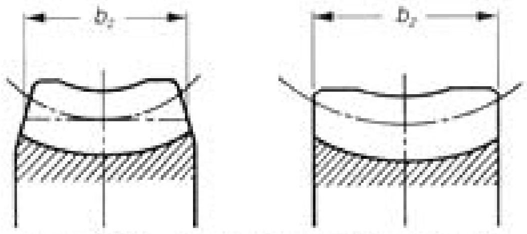

Fig. 17-13 Tooth Width of Worm Gear

17.5.5.B Zone Factor, Z

If $b_2 < 2.3 m_x \sqrt{Q+1}$, then:

$$Z = (\text{Basic zone factor}) \times \frac{b_2}{2\, m_x \sqrt{Q+1}} \qquad \textbf{(17-57)}$$

If $b_2 \ge 2.3 m_x \sqrt{Q+1}$, then:

$$Z = (\text{Basic zone factor}) \times 1.15$$

where: Basic Zone Factor is obtained from **Table 17-28**

Q : Diameter factor = $\frac{d_1}{m_x}$

Z_W: number of worm threads

17.5.5.C Sliding Speed Factor, K_v

The sliding speed factor is obtainable from **Figure 17-14**, where the abscissa is the pitch line linear velocity.

17.5.5.D Rotating Speed Factor, K_n

The rotating speed factor is presented in **Figure 17-15** as a function of the worm gear's rotating speed, n_2.

17.5.5.E Lubricant Factor, Z_L

Let Z_L = 1.0 if the lubricant is of proper viscosity and has antiscoring additives.

Some bearings in worm gear boxes may need a low viscosity lubricant. Then Z_L is to be less than 1.0. The recommended kinetic viscosity of lubricant is given in **Table 17-29**.

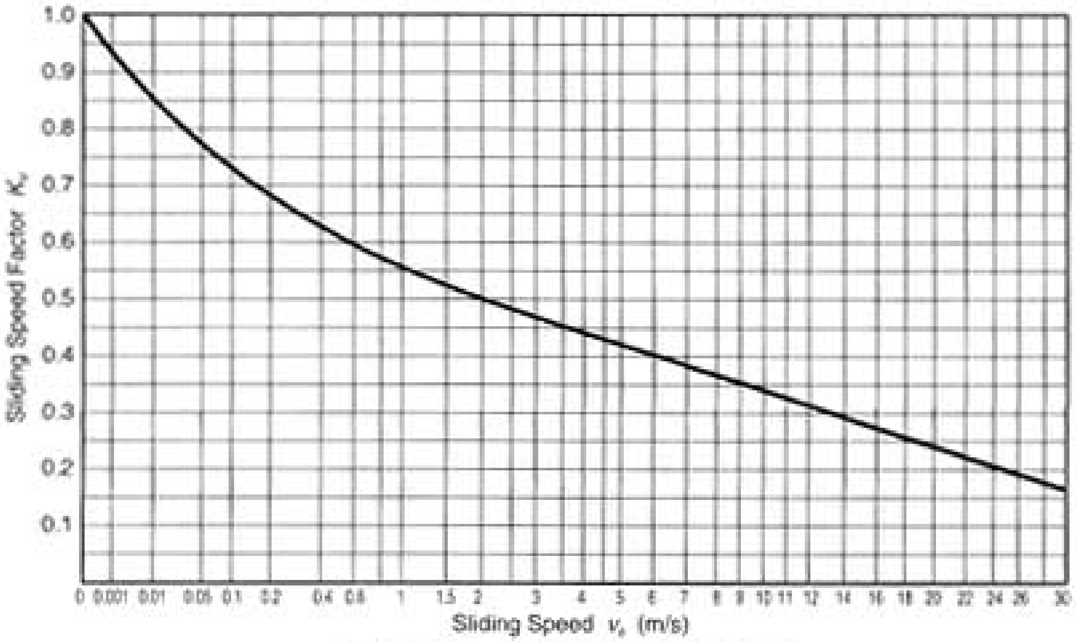

Fig. 17-14 Sliding Speed Factor, K_v

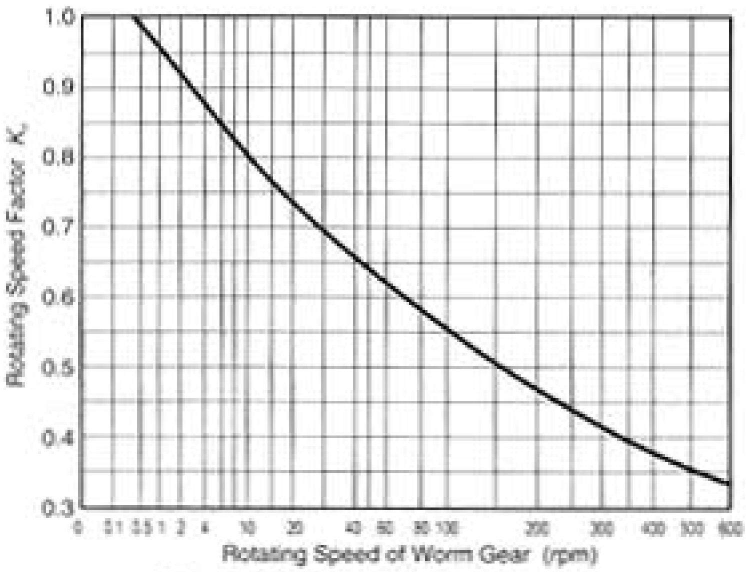

Fig. 17-15 Rotating Speed Factor, K_n

Table 17-29 Recommended Kinematic Viscosity of Lubricant Unit: cSt/37.8ºC

Operating lubricant Temperature		Sliding Speed (m/s)		
Highest Operating Temperature	**Lubricant Temperature at Start of Operation**	**Less than 2.5**	**2.5 to 5**	**More than 5**
0ºC to less than 10ºC	-10ºC ... 0ºC	110 ... 130	110 ... 130	110 ... 130
	more than 0ºC	110 ... 150	110 ... 150	110 ... 150
10ºC to less than 30ºC	more than 0ºC	200 ... 245	150 ... 200	150 ... 200
30ºC to less than 55ºC	more than 0ºC	350 ... 510	245 ... 350	200 ... 245
55ºC to less than 80ºC	more than 0ºC	510 ... 780	350 ... 510	245 ... 350
80ºC to less than 100ºC	more than 0ºC	900 ... 1100	510 ... 780	350 ... 510

17.5.5.F Lubrication Factor, Z_M

The lubrication factor, Z_M, is obtained from **Table 17-30**.

17.5.5.G Surface Roughness Factor, Z_R

This factor is concerned with resistance to pitting of the working surfaces of the teeth. Since there is insufficient knowledge about this phenomenon, the factor is assumed to be 1.0.

$$Z_R = 1.0 \qquad (17\text{-}58)$$

It should be noted that for **Equation (17-58)** to be applicable, surfaces roughness of the worm and worm gear must be less than 3 mm and 12 mm respectively. If either is rougher, the factor is to be adjusted to a smaller value.

17.5.5.H Contact Factor, K_C

Quality of tooth contact will affect load capacity dramatically. Generally, it is difficult to define precisely, but JIS B 1741 offers guidelines depending on the class of tooth contact.

$$\left.\begin{array}{ll} \text{Class A} & K_c = 1.0 \\ \text{Class B, C} & K_c > 1.0 \end{array}\right\} \quad \textbf{(17-59)}$$

Table 17-31 gives the general values of Kc depending on the JIS tooth contact class.

17.5.5.1 Starting Factor, K_S

This factor depends upon the magnitude of starting torque and the frequency of starts. When starting torque is less than 200% of rated torque, K_S factor is per **Table 17-32**.

17.5.5.J Time Factor, K_h

This factor is a function of the desired life and the impact environment. See **Table 17-33**. The expected lives in between the numbers shown in **Table 17-33** can be interpolated.

17.5.5.K Allowable Stress Factor, S_{clim}

Table 17-34 presents the allowable stress factors for various material combinations. Note that the table also specifies governing limits of sliding speed, which must be adhered to if scoring is to be avoided.

Table 17-30 Lubrication Factor, Z_M

Sliding Speed (m/s)	Less than 10	10 to 14	More than 14
Oil Bath Lubrication	1.0	0.85	-
Forced Circulation Lubrication	1.0	1.0	1.0

Table 17-31 Classes of Tooth Contact and General_Values of Contact Factor, K_C

Class	Proportion of Tooth Contact		K_C
	Tooth Width Direction	Tooth Height Direction	
A	More than 50%of Effective Width of Tooth	More than 40% of Effective Height of Tooth	1.0
B	More than 35% of Effective Width of Tooth	More than 30% of Effective Height of Tooth	1.3 ... 1.4
C	More than 20% of Effective Width of Tooth	More than 20% of Effective Height of Tooth	1.5 ... 1.7

Table 17-32 Starting Factor, K_S

Starting Factor	Starting Frequency per Hour			
	Less than 2	2 ... 5	5 ... 10	More than 10
K_S	1.0	1.07	1.13	1.18

Table 17-33 Time Factor, K_h

Impact from Prime Mover	Expected Life	K_h		
		Impact from Load		
		Uniform Load	Medium Impact	Strong Impact
Uniform Load (Motor, Turbine, Hydulic Motor)	1500 Hours	0.80	0.90	1.0
	5000 Hours	0.90	1.0	1.25
	26000 Hours*	1.0	1.25	1.50
	60000 Hours	1.25	1.50	1.75
Light Impact (Multicylinder engine)	1500 Hours	0.90	1.0	1.25
	5000 Hours	1.0	1.25	1.50
	26000 Hours*	1.25	1.50	1.75
	60000 Hours	1.50	1.75	2.0
Medium Impact (Single cylinder engine)	1500 Hours	1.0	1.25	1.50
	5000 Hours	1.25	1.50	1.75
	26000 Hours*	1.50	1.70	2.0
	60000 Hours	1.75	2.0	2.25

*__NOTE__: For a machine that operates 10 hours a day, 260 days a year; this number corresponds to ten years of operating life.

Table 17-34 Allowable Stress Factor for Surface Strength, S_{clim}

Material of worm Gear	Material of Worm	S_{clim}	Sliding Speed Limit before Scoring (m/s)*
Phosphor Bronze Centrifugal Casting	Alloy Steel Carburized & Quenched Alloy Steel HB 400 Alloy Steel HB 250	1.55 1.34 1.12	30 20 10
Phosphor Bronze Chilled Casting	Alloy Steel Carburized & Quenched Alloy Steel HB 400 Alloy Steel HB 250	1.27 1.05 0.88	30 20 10
Phosphor Bronze Sand Molding or Forging	Alloy Steel Carburized & Quenched Alloy Steel HB 400 Alloy Steel HB 250	1.05 0.84 0.70	30 20 10
Aluminum Bronze	Alloy Steel Carburized & Quenched Alloy Steel HB 400 Alloy Steel HB 250	0.84 0.67 0.56	20 15 10
Brass	Alloy Steel HB 400 Alloy Steel HB 250	0.49 0.42	8 5
Ductile Cast Iron	Ductile Cast Iron but with a higher hardness than the worm gear	0.70	5
Cast Iron (Perlitic)	Phosphor Bronze Casting and Forging	0.63	2.5
	Cast Iron but with a higher hardness than the worm gear	0.42	2.5

* Note: The value indicates the maximum sliding speed within the limit of the allowable stress factor, S_{clim}. Even when the allowable load is below the allowable stress level, if the sliding speed exceeds the indicated limit, there is danger of scoring gear surfaces.

17.5.6 Examples of worm Mesh Strength Calculation

Table 17-35A Worm and Worm Gears Design Details

No.	Item	Symbol	Unit	Worm	Worm Gear
1	Axial Module	m_x	mm	2	
2	Normal Pressure Angle	α_n	degree	20º	
3	No. of Threads, No. of Teeth	z_w, z_2		1	40
4	Pitch Diameter	d	mm	28	80
5	Lead Angle	γ	degree	4.08562	
6	Diameter Factor	Q		14	-
7	Tooth Width	b	mm	()	20
8	Manufacturing Method			Grinding	Hobbing
9	Surface Roughness			3.23 μm	12.5 μm
10	Revolutions per Minute	n	rpm	1500	37.5
11	Sliding Speed	v_s	m/s	2.205	
12	Material			S45C	Aι BC2
13	Heat Treatment			Induction Hardening	-
14	Surface Hardness			H_S 63 ... 68	-

Table 17-35 Surface Strength Factors and Allowable Force

No.	Item	Symbol	Unit	Worm Gear
1	Axial Module	m_x	mm	2
2	Worm Gear Pitch Diameter	d_2		80
3	Zone Factor	Z		1.5157
4	Sliding Speed Factor	K_v		0.49
5	Rotating Speed Factor	K_n		0.66
6	Lubricant Factor	Z_L		1.0
7	Lubrication Factor	Z_M		1.0
8	Surface Roughness Factor	Z_R		1.0
9	Contact Factor	K_C		1.0
10	Allowable Stress Factor	S_{Clim}		0.67
11	Allowable Tangential Force	F_{tlim}	kgf	83.5