Speed Reducers for Precision Motion Control

HarmonicDrive®

Reducer Catalog

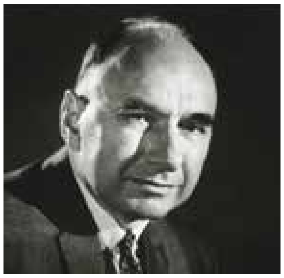
- Gear Units CSD
- Engineering Data

Excellent Technology for Evolving Industries

Harmonic Drive® actuators utilize high-precision, zero-backlash Harmonic Drive® precision gears and play critical roles in robotics, semiconductor manufacturing equipment, factory automation equipment, medical diagnostics and surgical robotics. Additionally, our products are frequently used in mission-critical spaceflight applications which capture the human spirit.

With over 50 years of experience, our expert engineering and production teams continually develop enabling technologies for the evolving motion control market. We are proud of our outstanding engineering capabilities and successful history of providing customer specific solutions to meet their application requirements.

Harmonic Drive LLC continues to develop enabling technologies for the evolving motion control market, which drives the pace of global innovation.



C. Walton Musser
Patented Strain Wave
Gearing in 1955

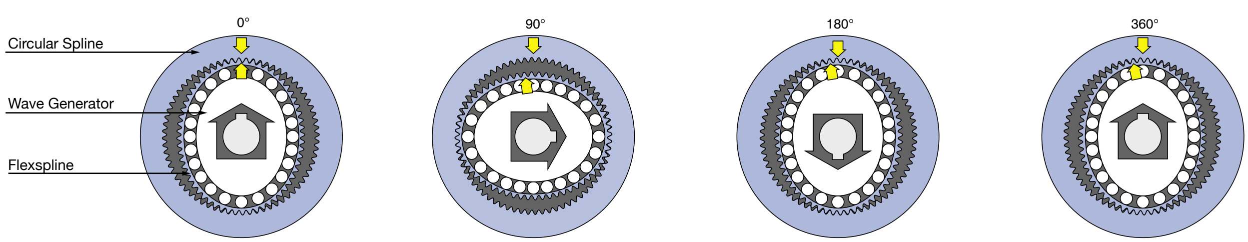
Operating Principle of HarmonicDrive® Gears

A simple three-element construction combined with the unique operating principle puts extremely high reduction ratio capabilities into a very compact and lightweight package. The high-performance attributes of this gearing technology including, zero-backlash, high-torque-to-weight ratio, compact size, and excellent positional accuracy, are a direct result of the unique operating principles.

Wave Generator
The Wave Generator is a thin, raced-ball bearing fitted onto an elliptical hub. This serves as a high-efficiency torque converter and is generally mounted onto the input or motor shaft.

Flexspline
The Flexspline is a non-rigid, thin cylindrical cup with external teeth on the open end of the cup. The Flexspline fits over the Wave Generator and takes on its elliptical shape. The Flexspline is generally used as the output of the gear.

Circular Spline
The Circular Spline is a rigid ring with internal teeth. It engages the teeth of the Flexspline across the major axis of the Wave Generator ellipse. The Circular Spline has two more teeth than the Flexspline and is generally mounted onto a housing.



The Flexspline is slightly smaller in diameter than the Circular Spline and usually has two fewer teeth than the Circular Spline. The elliptical shape of the Wave Generator causes the teeth of the Flexspline to engage the Circular Spline at two opposite regions across the major axis of the ellipse.

As the Wave Generator rotates the teeth of the Flexspline engage with the Circular Spline at the major axis.

For every 180 degree clockwise movement of the Wave Generator, the Flexspline rotates counterclockwise by one tooth in relation to the Circular Spline.

Each complete clockwise rotation of the Wave Generator results in the Flexspline moving counterclockwise by two teeth from its original position, relative to the Circular Spline. Normally, this motion is taken out as output.

■ Development of HarmonicDrive® Speed Reducers

Harmonic Drive® gears have been evolving since the strain wave gear was first patented in 1955. Our innovative development and engineering teams have led us to significant advances in our gear technology. In 1988, Harmonic Drive successfully designed and manufactured a new tooth profile, the "S" tooth. Since implementing the "S" tooth profile, improvement in life, strength and torsional stiffness have been realized. In the 1990s, we focused engineering efforts on designing gears featuring space savings, higher speed, higher load capacity and higher reliability. Then in the 2000s, significant reduction in size and thickness were achieved, all while maintaining high precision specifications.

HarmonicDrive®

CSD Series

Gear Unit CSD

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Features

CSD Gear Units

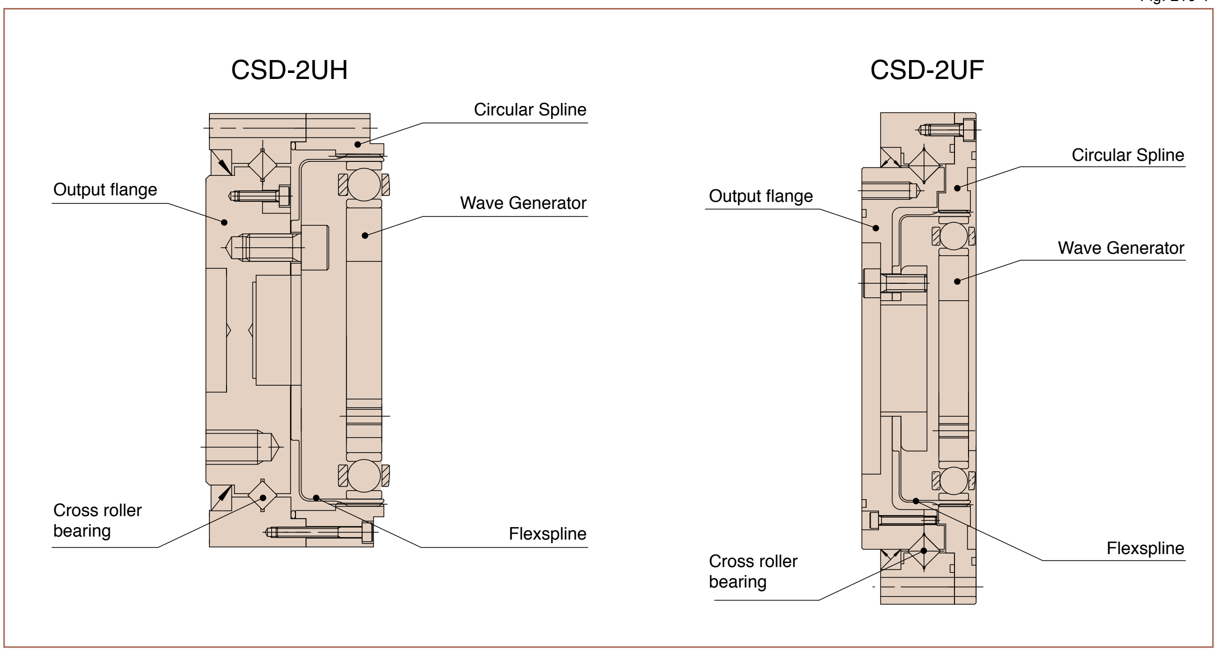
Available in two form factors, the CSD series gear units offer zero backlash while remaining lightweight and compact. These units are ideal for humanoid robots, aerospace, semiconductor equipment and many other critical applications. Ratios available are from 50:1 to 100:1.

Features

- Zero backlash
- Compact design
- Hollow shaft (2UF only)
- High-load capacity
- Lightweight

Structure of CSD Gear Unit

Fig. 210-1



Ordering Code

CSD - 20 - 100 - 2UH - SP

Table 211-1

Series	Size	Ratio*			Model	Special specification
CSD	14	50	80	100	2UH= Unit type (Size 14 to 50) 2UF= Hollow shaft (Size 14 to 40)	Blank= Standard product SP = Special specification code
	17	50	80	100		
	20	50	80	100		
	25	50	80	100		
	32	50	80	100		
	40	50	80	100		
	50	50	80	100		

* The reduction ratio value is based on the following configuration:
Input: wave generator, fixed: circular spline, output: flexspline

CSD-2UH Gear Unit

Size	Gear ratio	Rated torque at input speed 2000rpm		Limit for repeated peak torque		Limit for average torque		Limit for momentary peak torque		Maximum input speed (rpm)	Limit for average input speed (rpm)	Moment of inertia	
		Nm	kgfm	Nm	kgfm	Nm	kgfm	Nm	kgfm	Grease	Grease	$I \times 10^{-4} kgm^2$	$J \times 10^{-5} kgfms^2$
	50	3.7	0.38	12	1.2	4.8	0.49	24	2.4				
14	80	5.4	0.55	16	1.6	7.7	0.79	35	3.6	8500	3500	0.021	0.021
	100	5.4	0.55	19	1.9	7.7	0.79	35	3.6				
	50	11	1.1	23	2.3	18	1.8	48	4.9				
17	80	15	1.5	29	3.0	19	1.9	61	6.2	7300	3500	0.054	0.055
	100	16	1.6	37	3.8	27	2.8	71	7.2				
	50	17	1.7	39	4.0	24	2.4	69	7.0				
20	80	24	2.4	51	5.2	33	3.4	89	9.1	6500	3500	0.090	0.092
	100	28	2.9	57	5.8	34	3.5	95	9.7				
	50	27	2.8	69	7.0	38	3.9	127	13				
25	80	44	4.5	96	9.8	60	6.1	179	18	5600	3500	0.282	0.288
	100	47	4.8	110	11	75	7.6	184	19				
	50	53	5.4	151	15	75	7.6	268	27				
32	80	83	8.5	213	22	117	12	398	41	4800	3500	1.09	1.11
	100	96	9.8	233	24	151	15	420	43				
	50	96	9.8	281	29	137	14	480	49				
40	80	144	15	364	37	198	20	686	70	4000	3000	2.85	2.91
	100	185	19	398	41	260	27	700	71				
	50	172	18	500	51	247	25	1000	102				
50	80	260	27	659	67	363	37	1300	133	3500	2500	8.61	8.78
	100	329	34	686	70	466	48	1440	147				

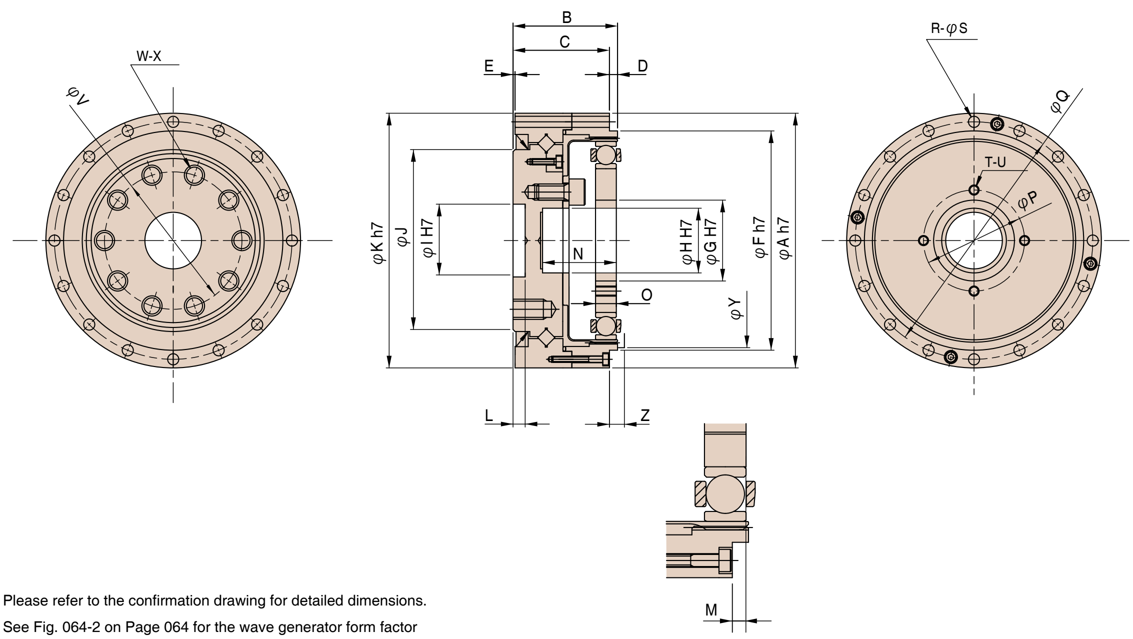
CSD-2UF Hollow Shaft Gear Unit

Size	Gear ratio	Rated torque at input speed 2000rpm		Limit for repeated peak torque		Limit for average torque		Limit for momentary peak torque		Maximum input speed (rpm)	Limit for average input speed (rpm)	Moment of inertia	
		Nm	kgfm	Nm	kgfm	Nm	kgfm	Nm	kgfm	Grease	Grease	$I \times 10^{-4} kgm^2$	$J \times 10^{-5} kgfms^2$
	50	3.7	0.38	12	1.2	4.8	0.49	24	2.4				
14	80	5.4	0.55	16	1.6	7.7	0.79	35	3.6	8500	3500	0.021	0.021
	100	5.4	0.55	19	1.9	7.7	0.79	35	3.6				
	50	11	1.1	23	2.3	18	1.8	48	4.9				
17	80	15	1.5	29	3.0	19	1.9	61	6.2	7300	3500	0.054	0.055
	100	16	1.6	37	3.8	27	2.8	71	7.2				
	50	17	1.7	39	4.0	24	2.4	69	7.0				
20	80	24	2.4	51	5.2	33	3.4	89	9.1	6500	3500	0.090	0.092
	100	28	2.9	57	5.8	34	3.5	95	9.7				
	50	27	2.8	69	7.0	38	3.9	127	13				
25	80	44	4.5	96	9.8	60	6.1	179	18	5600	3500	0.282	0.288
	100	47	4.8	110	11	75	7.6	184	19				
	50	53	5.4	151	15	75	7.6	268	27				
32	80	83	8.5	213	22	117	12	398	41	4800	3500	1.09	1.11
	100	96	9.8	233	24	151	15	420	43				
	50	96	9.8	281	29	137	14	480	49				
40	80	144	15	364	37	198	20	686	70	4000	3000	2.85	2.91
	100	185	19	398	41	260	27	700	71				

(Note) Moment of inertia: $I = \frac{1}{4} GD^2$

Outline dimensions CSD-2UH

Fig. 212-1



* Please refer to the confirmation drawing for detailed dimensions.

* See Fig. 064-2 on Page 064 for the wave generator form factor

Dimensions CSD-2UH

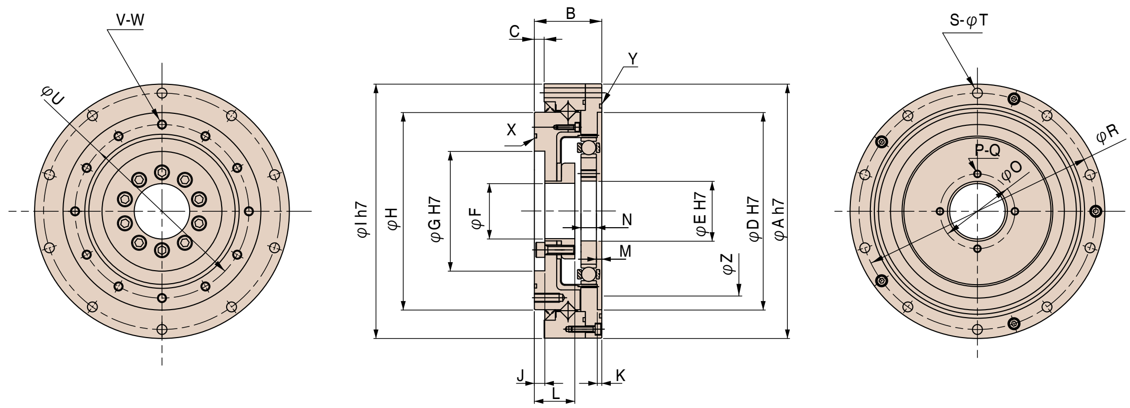
Table 212-1

Unit : mm

Symbol \ Size	14	17	20	25	32	40	50
φA h7	55	62	70	85	112	126	157
B	25	26.5	29.7	37.1	43	51.7	62.5
C	23	24.5	27.7	34.1	40	47.7	58.5
D	2	2	2	3	3	4	4
E	0.5	0.5	0.5	0.5	1	1	1
φF h7	42.5	49.5	58	73	96	108.5	136
φG H7	11	15	20	24	32	40	50
φH H7	11	11	16	20	30	32	44
φI H7	12	14	18	24	32	36	48
φJ	31	38	45	58	78	90	112
φK h7	55	62	70	85	112	126	157
L	5	5	5	5.5	5.5	6	7
M	$1.7^{+0.2}_{0}$	$1.7^{+0.2}_{0}$	$1.7^{+0.2}_{0}$	$2.6^{+0.2}_{0}$	$2.5^{+0.2}_{0}$	$3.4^{+0.2}_{0}$	$3.2^{+0.2}_{0}$
N	14.8	16.3	18.8	23.7	30.6	36.5	44.3
O	$4^{0}_{-0.1}$	$5^{0}_{-0.1}$	$5.2^{0}_{-0.1}$	$6.3^{0}_{-0.1}$	$8.6^{0}_{-0.1}$	$10.3^{0}_{-0.1}$	$12.7^{0}_{-0.1}$
φP (PCD)	17	21	26	30	40	50	60
φQ (PCD)	49	56	64	79	104	117.5	147
R	6	10	12	18	18	18	22
φS	3.4	3.4	3.4	3.4	4.5	5.5	6.6
T	4	4	4	4	4	4	4
U	M3	M3	M3	M3	M4	M5	M6
φV (PCD)	25	27	34	42	57	72	88
W	10	8	8	8	10	10	10
X	M3×7	M5×8	M6×9	M8×12	M8×12	M10×15	M12×18
φY	38	45	53	66	86	106	133
Z	3	3	3.5	4.5	5	6.5	7.5
Mass (kg)	0.35	0.46	0.65	1.2	2.4	3.6	6.9

Outline dimensions CSD-2UF

Fig. 213-1



* Please refer to the confirmation drawing for detailed dimensions.

* See Fig. 064-2 on Page 064 for the wave generator form factor

Dimensions CSD-2UF

Table 213-1

Unit : mm

Symbol \ Size	14	17	20	25	32	40
φA h7	70	80	90	110	142	170
B	22	22.7	26.8	31.5	37	45
C	0.5	0.5	2.3	2.1	2.8	6.5
φD H7	48	56	64	80	106	132
φE H7	11	15	20	24	32	40
φF	9	9	18	22	29	37
φG H7	30	34	40	52	70	80
φH	49	59	69	84	110	132
φI h7	70	80	90	110	142	170
J	4.9	5.4	4.8	5.5	6	7
K	2.5	2.5	2.5	3	3	3
L	12.9	13.4	16.8	19.5	22	27
M	$2.8^{+0.2}_{0}$	$2.8^{+0.2}_{0}$	$2.8^{+0.2}_{0}$	$3.4^{+0.2}_{0}$	$3.5^{+0.2}_{0}$	$3.6^{+0.2}_{0}$
N	$4^{0}_{-0.1}$	$5^{0}_{-0.1}$	$5.2^{0}_{-0.1}$	$6.3^{0}_{-0.1}$	$8.6^{0}_{-0.1}$	$10.3^{0}_{-0.1}$
φO (PCD)	17	21	26	30	40	50
P	4	4	4	4	4	4
Q	M3	M3	M3	M3	M4	M5
φR (PCD)	64	74	84	102	132	158
S	6	8	8	10	10	10
φT	3.4	3.4	3.4	4.5	5.5	6.6
φU (PCD)	42	50	60	73	96	116
V	8	10	8	8	8	12
W	M3×5	M3×6	M4×8	M5×8	M6×10	M6×10
X	34.5×0.80	38.0×1.50	S48	S60	S80	S100
Y	49.0×1.50	59.4×1.20	S70	S85	S115	S140
φZ	38	45	53	66	86	106
Mass (kg)	0.50	0.66	0.94	1.7	3.3	5.7

Gear Unit CSD

Positional accuracy

See "Engineering data" for a description of terms.

Table 214-1

Size		14	17	20	25	32	40	50
Positional Accuracy	×10⁻⁴ rad	4.4	4.4	2.9	2.9	2.9	2.9	2.9
	arc min	1.5	1.5	1.0	1.0	1.0	1.0	1.0

Hysteresis loss

See "Engineering data" for a description of terms.

Table 214-2

Ratio	Unit \ Size	14	17	20	25	32	40	50
50	$\times10^{-4}$ rad	7.3	4.4	4.4	4.4	4.4	4.4	4.4
	arc min	2.5	1.5	1.5	1.5	1.5	1.5	1.5
80 or more	$\times10^{-4}$ rad	5.8	2.9	2.9	2.9	2.9	2.9	2.9
	arc min	2.0	1.0	1.0	1.0	1.0	1.0	1.0

Torsional stiffness

See "Engineering data" for a description of terms.

Table 214-3

Item		Unit \ Size	14	17	20	25	32	40	50
	T_1	Nm	2.0	3.9	7.0	14	29	54	108
		kgfm	0.2	0.4	0.7	1.4	3.0	5.5	11
	T_2	Nm	6.9	12	25	48	108	196	382
		kgfm	0.7	1.2	2.5	4.9	11	20	39
Reduction ratio 50	K_1	$\times10^{4}$ Nm/rad	0.29	0.67	1.1	2.0	4.7	8.8	17
		kgfm/arc min	0.085	0.2	0.32	0.6	1.4	2.6	5.0
	K_2	$\times10^{4}$ Nm/rad	0.37	0.88	1.3	2.7	6.1	11	21
		kgfm/arc min	0.11	0.26	0.4	0.8	1.8	3.4	6.3
	K_3	$\times10^{4}$ Nm/rad	0.47	1.2	2.0	3.7	8.4	15	30
		kgfm/arc min	0.14	0.34	0.6	1.1	2.5	4.5	9.0
	θ_1	$\times10^{-4}$ rad	6.9	5.8	6.4	7.0	6.2	6.1	6.4
		arc min	2.4	2.0	2.2	2.4	2.1	2.1	2.2
	θ_2	$\times10^{-4}$ rad	19	14	19	18	18	18	18
		arc min	6.4	4.6	6.6	6.1	6.1	5.9	6.2
Reduction ratio 80 or more	K_1	$\times10^{4}$ Nm/rad	0.4	0.84	1.3	2.7	6.1	11	21
		kgfm/arc min	0.12	0.25	0.4	0.8	1.8	3.2	6.3
	K_2	$\times10^{4}$ Nm/rad	0.44	0.94	1.7	3.7	7.8	14	29
		kgfm/arc min	0.13	0.28	0.5	1.1	2.3	4.2	8.5
	K_3	$\times10^{4}$ Nm/rad	0.61	1.3	2.5	4.7	11	20	37
		kgfm/arc min	0.18	0.39	0.75	1.4	3.3	5.8	11
	θ_1	$\times10^{-4}$ rad	5.0	4.6	5.4	5.2	4.8	4.9	5.1
		arc min	1.7	1.6	1.8	1.8	1.7	1.7	1.7
	θ_2	$\times10^{-4}$ rad	16	13	15	13	14	14	13
		arc min	5.4	4.3	5.0	4.5	4.8	4.8	4.6

* The values in this table are reference values. The minimum value is approximately 80% of the displayed value.

Starting torque

See "Engineering data" for a description of terms. The values in the table below vary depending on the use conditions, use them as reference values.

■ CSD-2UH

Table 214-4
Unit: Ncm

Ratio \ Size	14	17	20	25	32	40	50
50	4.4	6.7	8.9	16	32	55	102
80	3.2	4.4	5.7	10	22	36	68
100	2.8	3.8	5.1	9.1	20	32	60

■ CSD-2UF

Table 214-5
Unit: Ncm

Ratio \ Size	14	17	20	25	32	40
50	5.3	7.5	9.7	17	34	58
80	3.8	4.9	6.2	11	23	37
100	3.2	4.2	5.5	9.6	21	33

Backdriving torque

See "Engineering data" for a description of terms. The values in the table below vary depending on the use conditions, use them as reference values.

CSD-2UH

Table 215-1
Unit: Nm

Ratio \ Size	14	17	20	25	32	40	50
50	2.9	4.3	5.2	9.5	19	33	61
80	2.9	4.1	5.7	10	21	35	66
100	3.5	4.6	6.0	11	23	38	71

CSD-2UF

Table 215-2
Unit: Nm

Ratio \ Size	14	17	20	25	32	40
50	3.3	4.7	5.6	10	20	34
80	3.3	4.5	6.1	10	22	36
100	3.9	5.0	6.4	11	24	39

Ratcheting torque

See "Engineering data" for a description of terms.

Table 215-3
Unit: Nm

Ratio \ Size	14	17	20	25	32	40	50
50	60	105	150	315	685	1260	2590
80	75	140	245	475	980	1960	3780
100	55	110	180	350	700	1470	2870

Buckling torque

See "Engineering data" for a description of terms.

Table 215-4
Unit: Nm

Size	14	17	20	25	32	40	50
All ratios	190	330	560	1000	2200	4300	8000

No-load running torque

No-load running torque is the torque which is required to rotate the input side (high speed side), when there is no load on the output side (low speed side).

Measurement condition

Table 216-1

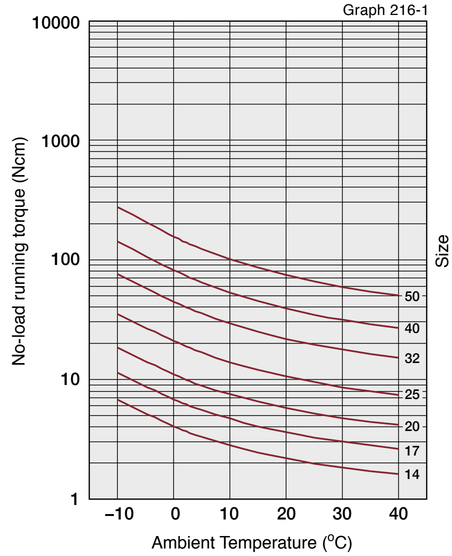
Ratio 100			
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A (size 20 or larger)
			Harmonic Grease SK-2 (size 14, 17)
		Quantity	Recommended quantity
Torque value is measured after 2 hours at 2000rpm input.			

■ No-load running torque for a reduction ratio of 100:1

■ CSD-2UH

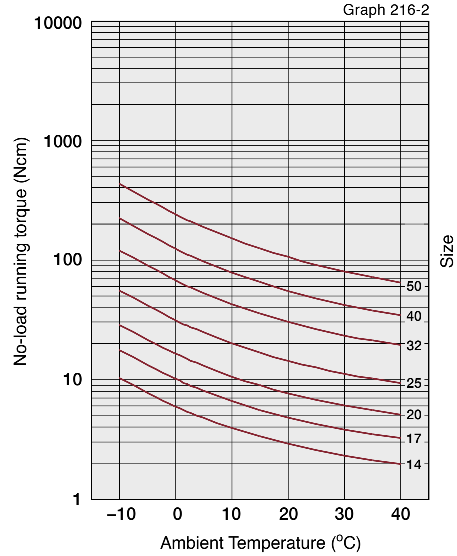
Input speed: 500rpm

Graph 216-1



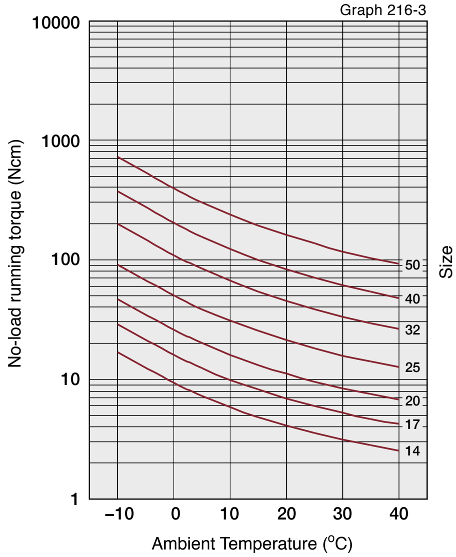
Input speed: 1000rpm

Graph 216-2



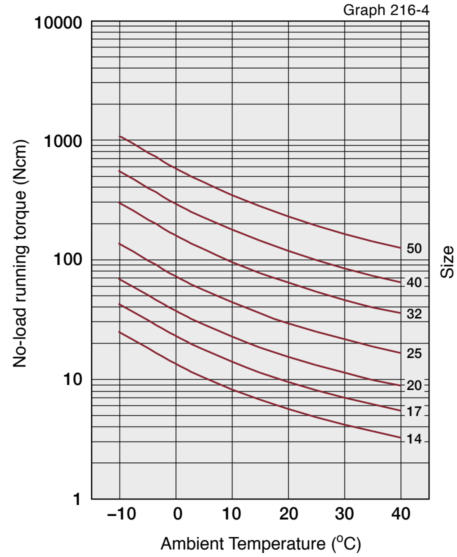
Input speed: 2000rpm

Graph 216-3



Input speed: 3500rpm

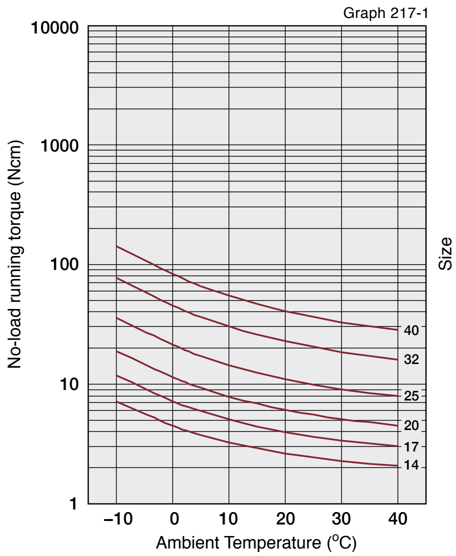
Graph 216-4



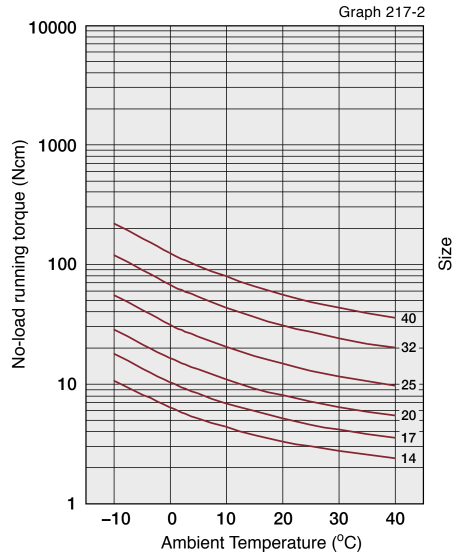
*The values in this graph are average values ($\overline{X}$). σ≈20%

■ CSD-2UF

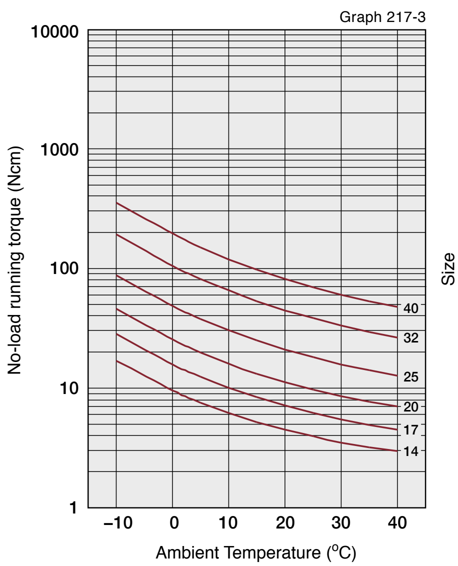
Input speed: 500rpm



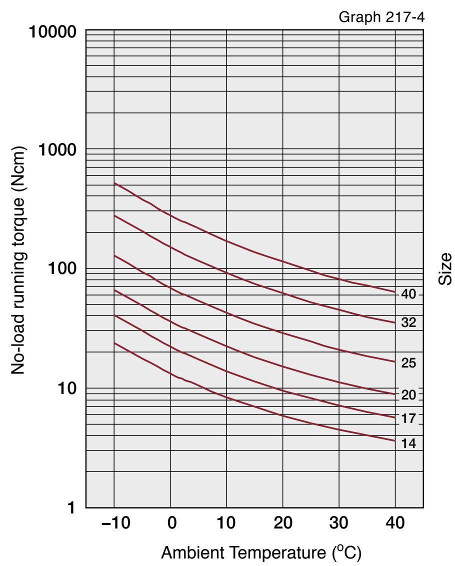
Input speed: 1000rpm



Input speed: 2000rpm



Input speed: 3500rpm



*The values in this graph are average values ($\overline{X}$). σ≈20%

■ Compensation value in each ratio

No-load running torque of the gear varies with ratio.
The graphs indicate a value for ratio 100.
For other gear ratios, add the compensation values from table on the right.

Table 217-1

No-load running torque compensation values

Unit: Ncm

Size \ Ratio	2UH		2UF	
	50	80	50	80
14	+0.93	+0.2	+1.4	+.03
17	+1.5	+0.3	+1.8	+0.4
20	+2.3	+0.4	+2.6	+0.5
25	+3.8	+0.7	+4.3	+0.8
32	+7.3	+1.3	+8.2	+1.5
40	+12	+2.1	+14	+2.5
50	+22	+3.8	–	–

Efficiency

The efficiency varies depending on the following:

- Reduction ratio
- Input rotational speed
- Load torque
- Temperature
- Lubrication (Type and quantity)

Measurement condition

Table 218-1

Installation	Based on recommended tolerance		
Load torque	The rated torque shown in the rating table (see Page 211)		
* When load torque is lower than rated torque, the efficiency value gets low. See efficiency compensation coefficient below.			
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A
			Harmonic Grease SK-2
		Quantity	Recommended quantity

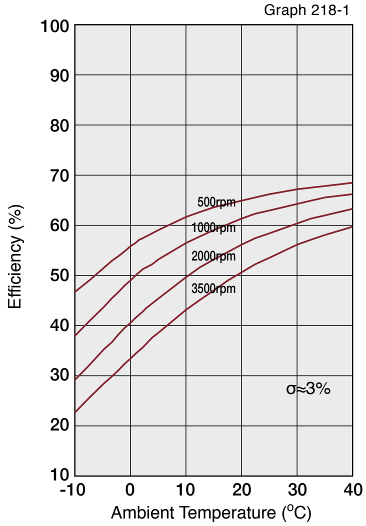
Note: Please contact us for details pertaining to recommended oil lubricant for CSD.

Efficiency at rated torque

CSD-2UH

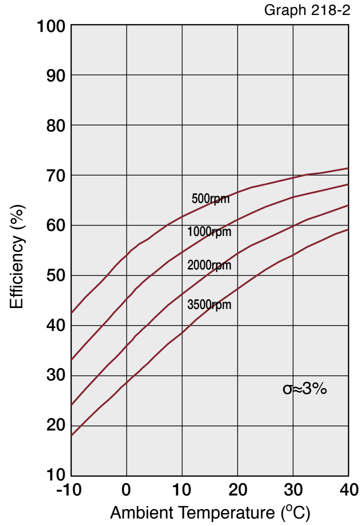
Size 14/ Ratio 50

Graph 218-1



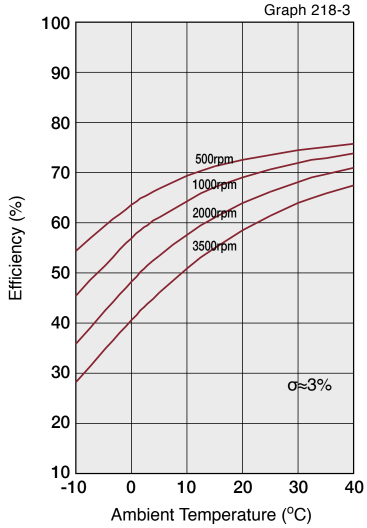
Size 14/ Ratio 80, 100

Graph 218-2



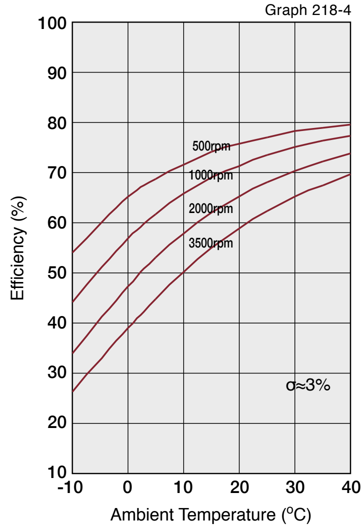
Size 17 to 50/ Ratio 50

Graph 218-3



Size 17 to 50/ Ratio 80, 100

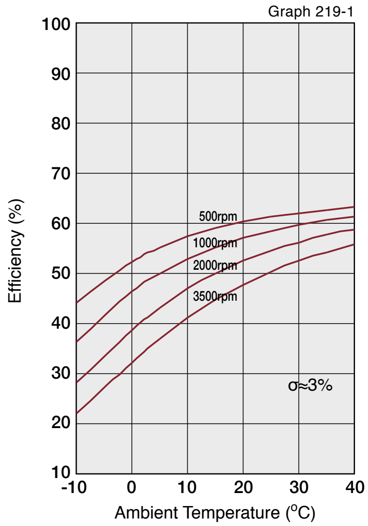
Graph 218-4



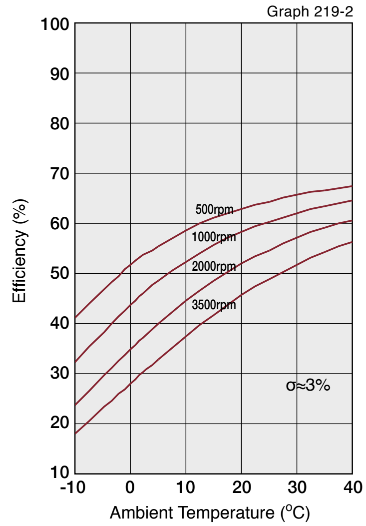
*The values in this graph are average values ($\bar{X}$). σ≈20%

■ CSD-2UF

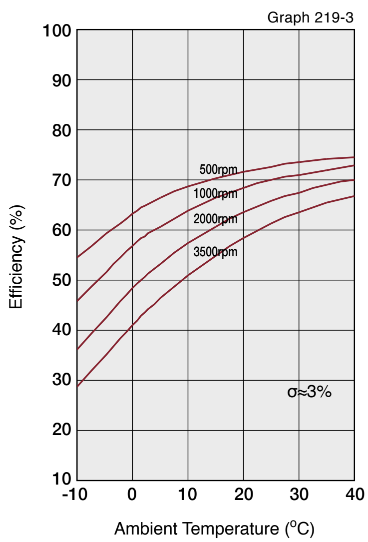
Size 14/ Ratio 50



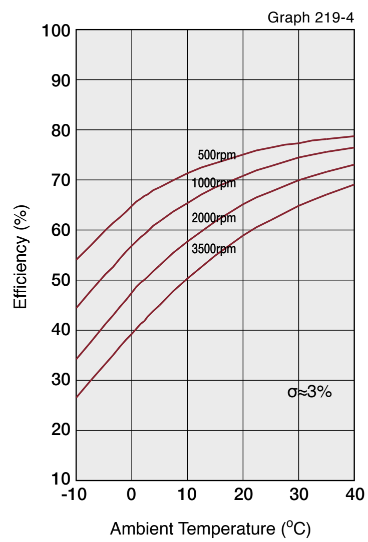
Size 14/ Ratio 80, 100



Size 17 to 40/ Ratio 50



Size 17 to 40/ Ratio 80, 100



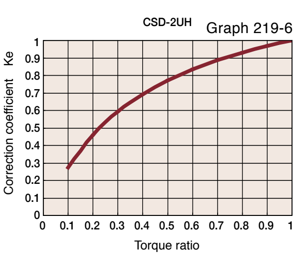
*The values in this graph are average values ($\bar{X}$). σ≈20%

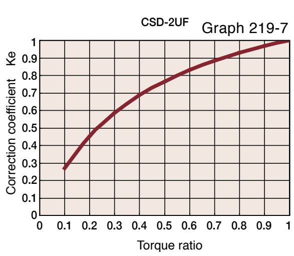
■ Efficiency compensation coefficient

If the load torque is smaller than the rated torque, the efficiency compensation. Calculate compensation coefficient Ke from the efficiency correction coefficient graphs of Graph 219-6 and 219-7 to calculate the efficiency using the following example.

* Efficiency compensation coefficient Ke=1 holds when the load torque is greater than the rated torque.

Torque ratio α is the value of load torque/rated torque (Rating table: Page 211).





■ Efficiency compensation coefficient

When the load torque is lower than the rated torque, calculate the efficiency from the following formula.

Formula 219-1

$$\text{Efficiency } \eta = Ke \times (\eta_R + \eta e)$$

Symbols of the calculation formula 219-1

Table 219-1

η	Efficiency	————
Ke	Efficiency compensation coefficient	See Graph 219-6, 219-7.
η_R	Efficiency at the rated torque	See Graph 218-1 through 219-5.

Calculation Example

Efficiency η (%) under the following condition is obtained from the example of CSD-20-50-2UH.

Input rotational speed: 1000 rpm — Load torque: 13.6 Nm
Lubrication: Grease lubrication — Lubricant temperature: 20°C
Efficiency compensation coefficient: 0.95: (the torque ratio α =13.6/17=0.8, Graph 219-6

Efficiency η (%) = 0.95×62 (from Graph 218-1) =58.9%

Checking output bearing

A precision cross roller bearing is built in the gear unit to directly support the external load (output flange).
Check the maximum moment load, life of the bearing and static safety coefficient to fully bring out the performance of the unit type.
See Page 030 to 034 of "Engineering data" for each calculation formula.

■ Checking procedure

(1) Checking the maximum moment load (Mmax)

Calculate the maximum moment load (M*max*). → Maximum moment load (M*max*) ≦ allowable moment (Mc)

(2) Checking the life

Calculate the radial load (Fr*av*) and the average axial load (Fa*av*). → Calculate the radial load coefficient (x) and the axial load coefficient (y). → Calculate the lifetime

(3) Checking the static safety coefficient

Calculate the static equivalent radial load coefficient (Po). → Check the static safety coefficient. (fs)

■ Output bearing specifications

The specifications of the cross roller bearing are shown in Table 220-1 and -2.

■ CSD-2UH

Table 220-1

Size	Pitch circle dia. of a roller	Offset	Basic rated load				Allowable moment load Mc		Moment stiffness Km		Allowable axial load Fa	Allowable radial load Fr
	dp	R	Basic dynamic rated load C		Basic static rated load Co		Nm	kgfm	×10⁴	kgfm		
	m	m	×10²N	kgf	×10²N	kgf			Nm/rad	/arc-min	×10²N	×10²N
14	0.035	0.0095	47	480	60.7	620	41	4.2	4.38	1.3	10.1	6.74
17	0.0425	0.0099	52.9	540	75.5	770	64	6.5	7.75	2.3	11.3	7.58
20	0.050	0.0102	57.8	590	90	920	91	9.3	12.8	3.8	12.4	8.28
25	0.062	0.0130	96.0	980	151	1540	156	16	24.2	7.2	20.5	13.8
32	0.080	0.0144	150	1530	250	2550	313	32	53.9	16	32.1	2.15
40	0.096	0.0151	213	2170	365	3720	450	46	91	27	45.6	3.05
50	0.119	0.0192	348	3550	602	6140	759	77	171	51	74.4	4.99

■ CSD-2UF

Table 220-2

Size	Pitch circle dia. of a roller	Offset	Basic rated load				Allowable moment load Mc		Moment stiffness Km		Allowable axial load Fa	Allowable radial load Fr
	dp	R	Basic dynamic rated load C		Basic static rated load Co		Nm	kgfm	×10⁴	kgfm		
	m	m	×10²N	kgf	×10²N	kgf			Nm/rad	/arc-min	×10²N	×10²N
14	0.050	0.0118	57.8	590	90	920	91	9.3	12.8	3.8	12.4	8.28
17	0.060	0.0123	104	1060	163	1670	124	12.6	15.4	4.6	22.2	14.9
20	0.070	0.0128	146	1490	220	2250	187	19.1	25.2	7.5	31.2	20.9
25	0.085	0.0134	218	2230	358	3660	258	26.3	39.2	11.6	46.6	31.2
32	0.111	0.0168	382	3900	654	6680	580	59.1	100	29.6	81.7	54.7
40	0.133	0.0215	433	4410	816	8330	849	86.6	179	53.2	92.6	62.0

(Note)
* The basic dynamic rated load is the static radial load needed to result in a basic dynamic rated life of one million rotations.
* The basic static rated load is the static load that produces a contact stress of 4 kN/mm2 in the center of the contact area between the rolling element receiving the maximum load.
* The moment stiffness value is an average.
* Allowable moment load is the maximum moment load that may be applied to the output shaft. Please adhere to these values for optimum performance. Moment stiffness is a reference value. The minimum value is approximately 80% of the displayed value.
* Allowable axial or radial load is the value that satisfies the reducer life when either a radial load or an axial load is applied to the main shaft. (When radial load is Lr+R=0mm, and axial load is La=0mm)

Output bearing and housing tolerances

Input: Wave generator
Output: Circular spline
Fixed: Flexspline

CSD-2UH

Fig. 221-1

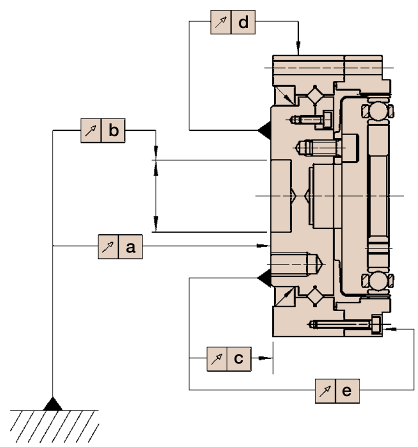


Table 221-1
Unit: mm

Symbol \ Size	14	17	20	25	32	40	50
a	0.010	0.010	0.010	0.015	0.015	0.015	0.018
b	0.010	0.012	0.012	0.013	0.013	0.015	0.015
c	0.007	0.007	0.007	0.007	0.007	0.007	0.007
d	0.010	0.010	0.010	0.010	0.010	0.015	0.015
e	0.025	0.025	0.025	0.035	0.037	0.037	0.040

CSD-2UF

Fig. 221-2

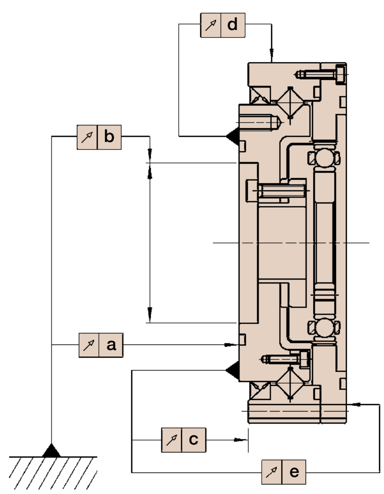


Table 221-2
Unit: mm

Symbol \ Size	14	17	20	25	32	40
a	0.010	0.010	0.010	0.015	0.015	0.015
b	0.010	0.010	0.010	0.010	0.013	0.013
c	0.010	0.010	0.010	0.010	0.013	0.013
d	0.010	0.010	0.010	0.010	0.013	0.013
e	0.031	0.031	0.031	0.041	0.047	0.047

Gear Unit CSD

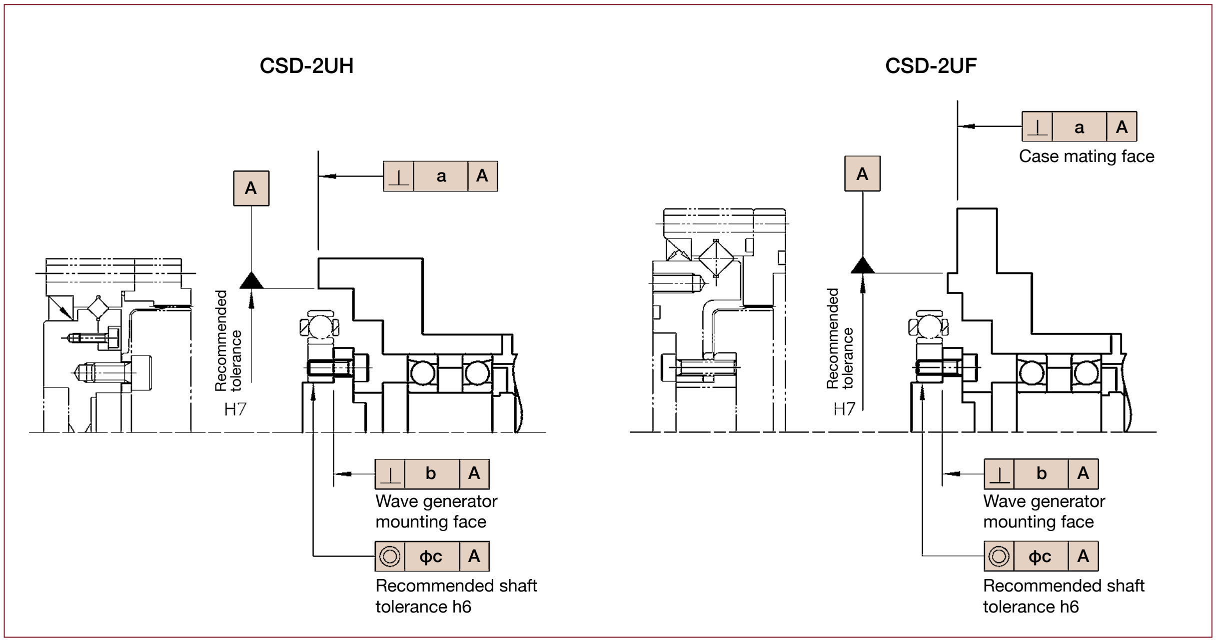
Recommended tolerances for assembly

For peak performance of the gear, it is essential that the following tolerances be observed when assembly is complete.
Pay careful attention to the following points and maintain the recommended assembly tolerances to avoid grease leakage.

- Warping and deformation on the mounting surface
- Contamination due to foreign matter
- Burrs, raised surfaces and location around the tap area of the mounting holes
- Insufficient chamfering on the mounting pilot joint
- Insufficient radii on the mounting pilot joint

Recommended Tolerances for Assembly

Fig. 222-1



Tolerances for Assembly CSD-2UH

Table 222-1
Unit: mm

Symbol \ Size	14	17	20	25	32	40	50
a	0.011	0.015	0.017	0.024	0.026	0.026	0.028
b	0.008	0.010	0.012	0.012	0.012	0.012	0.015
φc	0.016	0.018	0.019	0.022	0.022	0.024	0.030

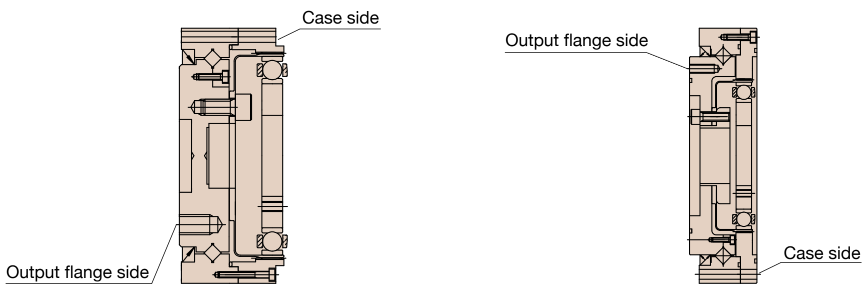
Tolerances for Assembly CSD-2UF

Table 222-2
Unit: mm

Symbol \ Size	14	17	20	25	32	40
a	0.011	0.015	0.017	0.024	0.026	0.026
b	0.008	0.010	0.012	0.012	0.012	0.012
φc	0.016	0.018	0.019	0.022	0.022	0.024

Installation and transmission torque

Fig. 223-1



■ Installation on output flange side and resulting transmission torque

■ CSD-2UH

Table 223-1

Item \ Size		14	17	20	25	32	40	50
Number of bolts		10	8	8	8	10	10	10
Bolt size		M3	M5	M6	M8	M8	M10	M12
Pitch circle	mm	25	27	34	42	57	72	88
Bolt tightening torque	Nm	2.4	10.8	18.4	44	44	74	128
Torque transmission capacity (bolt only)	Nm	50	122	217	486	824	1665	2933

■ CSD-2UF

Table 223-2

Item \ Size		14	17	20	25	32	40
Number of bolts		8	10	8	8	8	12
Bolt size		M3	M3	M4	M5	M6	M6
Pitch circle	mm	42	50	60	73	96	116
Bolt tightening torque	Nm	2.4	2.4	5.4	10.8	18.4	18.4
Torque transmission capacity (bolt only)	Nm	70	104	167	329	765	1109

■ Bolt connection to case side and resulting transmission torque

■ CSD-2UH

Table 223-3

Item \ Size		14	17	20	25	32	40	50
Number of bolts		6	10	12	18	18	18	22
Bolt size		M3	M3	M3	M3	M4	M5	M6
Pitch circle	mm	49	56	64	79	104	117.5	147
Bolt tightening torque	Nm	2.4	2.4	2.4	2.4	5.4	10.8	18.4
Torque transmission capacity (bolt only)	Nm	43	82	112	207	461	833	1804

■ CSD-2UF

Table 223-4

Item \ Size		14	17	20	25	32	40
Number of bolts		6	8	8	10	10	10
Bolt size		M3	M3	M3	M4	M5	M6
Pitch circle	mm	64	74	84	102	132	158
Bolt tightening torque	Nm	2.4	2.4	2.4	5.4	10.8	18.4
Torque transmission capacity (bolt only)	Nm	80	123	140	359	743	1259

(Table 223-1 **to** 223-4/Notes)
1. The material of the thread must withstand the clamp torque.
2. Recommended bolt: JIS B 1176 socket head cap screw / Strength range : JIS B 1051 over 12.9
3. Torque coefficient: K=0.2
4. Clamp coefficient: A=1.4
5. Tightening friction coefficient **μ**=0.15

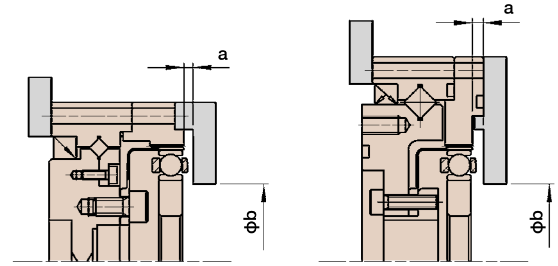
Gear Unit CSD

Lubrication

Grease lubrication is standard for the CSD-2UH and CSD-2UF. There is no need to add or apply grease upon installation since the products are shipped with the grease applied.

See table below for recommended housing dimensions. These dimensions must be maintained to prevent damage to the gear and to maintain a proper grease cavity.

Fig. 224-1



■ Recommended housing dimensions

Table 224-1
Unit: mm

Symbol \ Size	14	17	20	25	32	40	50
a*	1	1	1.5	1.5	2	2.5	3.5
a**	3	3	4.5	4.5	6	7.5	10.5
$\phi b^{+0.5}_{0}$	16	26	30	37	37	45	45

* For the wave generator facing downward
** For the wave generator facing upward

■ Compatible grease by size

Compatible grease varies depending on the size and reduction ratio. See the following compatibility table. We recommend SK-1A and SK-2 for general use.
See "Engineering data" on Page 016 for details for grease.

Compatible grease

Table 224-2

Size	14	17	20	25	32	40	50
SK-1A	—	—	○	○	○	○	○
SK-2	○	○	△	△	△	△	△
4BNo.2	□	□	□	□	□	□	□

○ mark: Standard grease
△ mark: Semi-standard grease
□ mark: Recommended grease for long life and high load

Sealing

The following sealing mechanism is required to prevent grease leakage and maintain the high durability of the gear.

- Rotating Parts .... Oil seal (with a spring). Surface should be smooth (no scratches).
- Mating flange .... O-ring and seal adhesive. Take care regarding distortion on the plane and how the O-ring is engaged.
- Screw hole area .... Screws should have a thread lock (Locktite 242 is recommended) or seal adhesive.

(Note) If you use Harmonic Grease® 4BNo.2 lubrication, strict sealing is required.

Sealing area and the recommended sealing method for the unit type

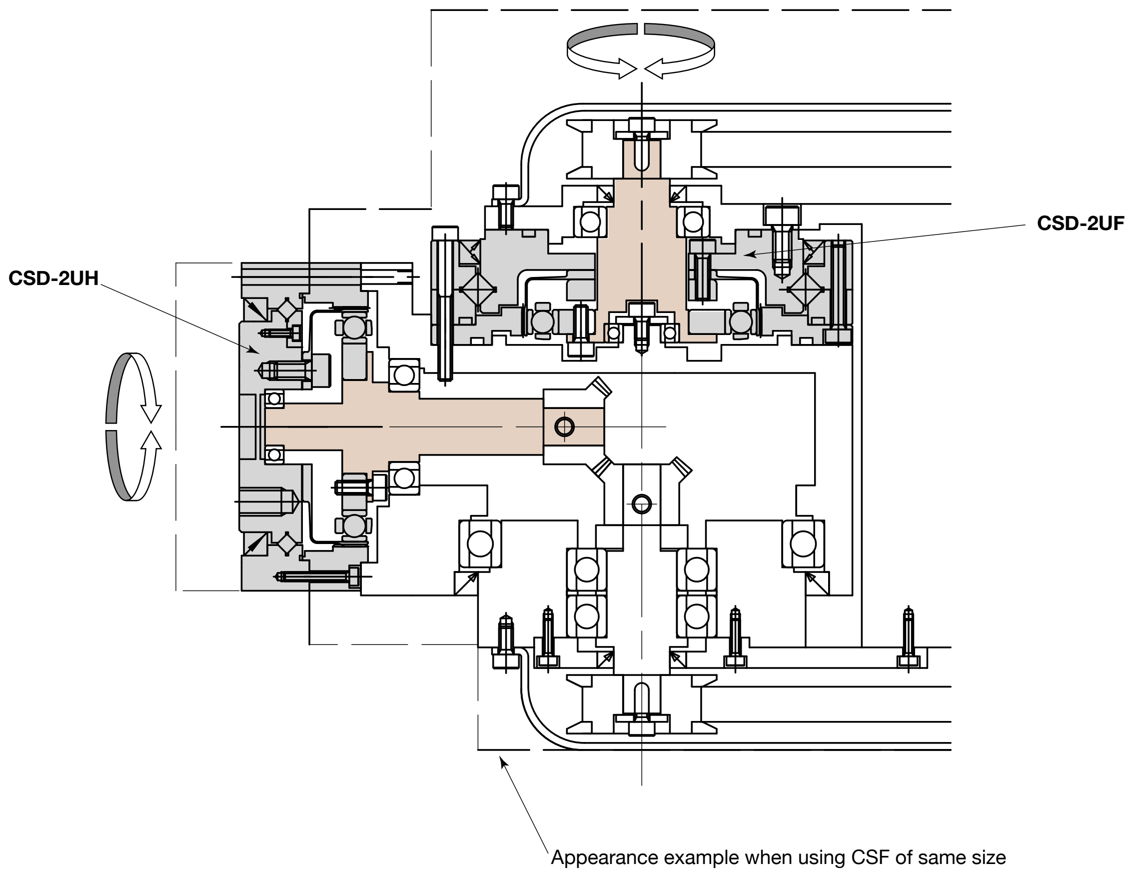
Table 224-3

Area requiring sealing		Recommended sealing method
Output side	Pass-through hole in the center of the output flange and the output flange mating face	Use O-ring (supplied with the product)
	Mounting screw area	Screw lock agent with sealing effect (Locktite 242 is recommended)
Input side	Flange mating face	Use O-ring (supplied with the product)
	Motor output shaft	Please select a motor which has an oil seal on the output shaft.

Application

Bending and twisting drive of the wrist for a vertical multijoint robot

Fig. 225-1



Engineering Data

Engineering Data

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- S tooth profile 009

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- Pancake style 011

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Tooth Profile

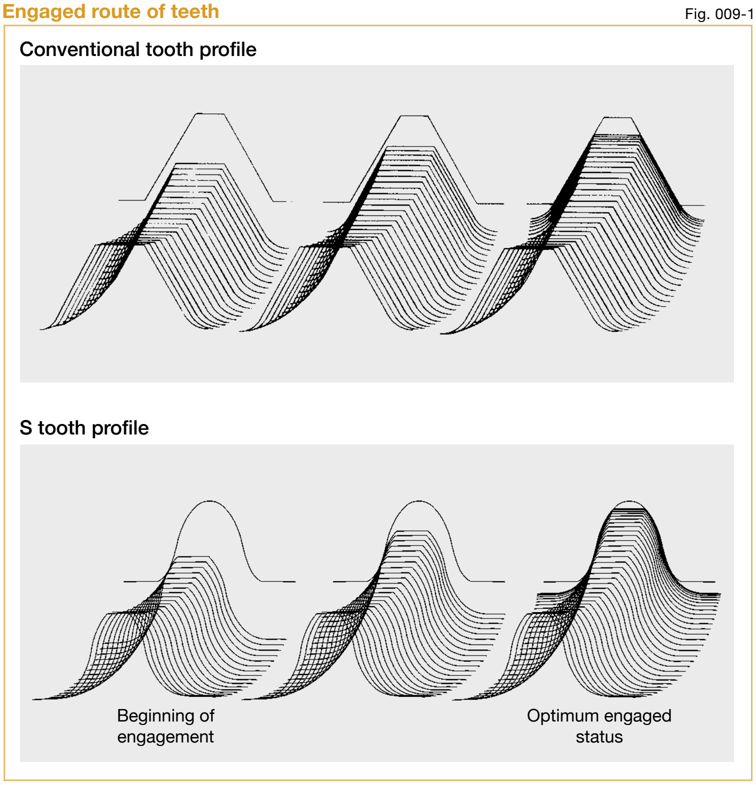
■ S tooth profile

Harmonic Drive developed a unique gear tooth profile that optimizes the tooth engagement. It has a special curved surface unique to the S tooth profile that allows continuous contact with the tooth profile. It also alleviates the concentration of stress by widening the width of the tooth groove against the tooth thickness and enlarging the radius on the bottom. This tooth profile (the “S tooth”) enables up to 30% of the total number of teeth to be engaged simultaneously.

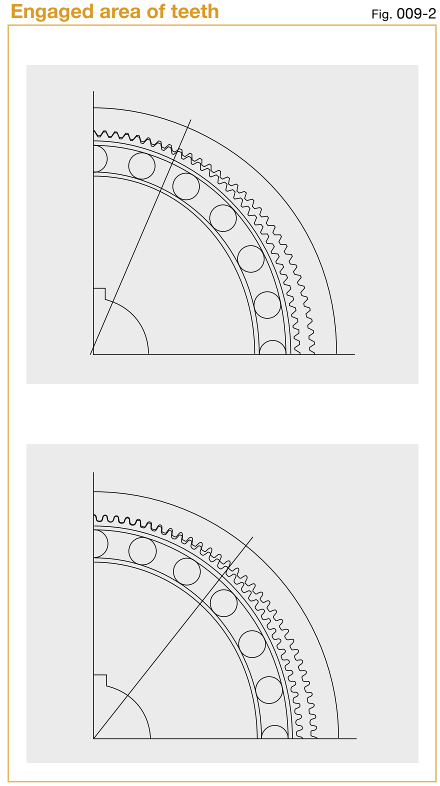
Additionally the large tooth root radius increases the tooth strength compared with an involute tooth. This technological innovation results in high torque, high torsional stiffness, long life and smooth rotation.

*Patented

Engaged route of teeth Fig. 009-1



Engaged area of teeth Fig. 009-2



Rotational direction and reduction ratio

Cup Style

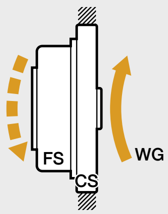
Series: CSG, CSF, CSD, CSF-mini

■ Rotational direction

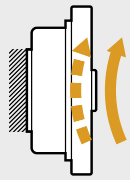
Fig. 010-1

*R indicates the reduction ratio value from the ratings table.

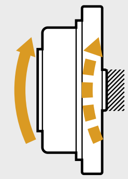
(Note) Contact us if you use the product as Accelerator (5) and (6).

1


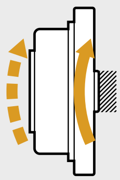
(1) Reducer
Input: Wave Generator (WG)
Output: Flexspline (FS)
Fixed: Circular Spline (CS)
$i=\frac{-1}{R}$

2


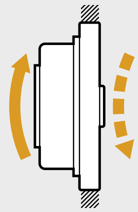
(2) Reducer
Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline
$i=\frac{1}{R+1}$

3


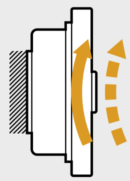
(3) Reducer
Input: Flexspline
Output: Circular Spline
Fixed: Wave Generator
$i=\frac{R}{R+1}$

4


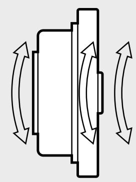
(4) Overdrive
Input: Circular Spline
Output: Flexspline
Fixed: Wave Generator
$i=\frac{R+1}{R}$

5


(5) Overdrive
Input: Flexspline
Output: Wave Generator
Fixed: Circular Spline
$i=-R$

6


(6) Overdrive
Input: Circular Spline
Output: Wave Generator
Fixed: Flexspline
$i=R+1$

7


(7) Differential
When all of the wave generator, the flexspline and the circular spline rotate, combinations (1) through (6) are available.

Silk hat

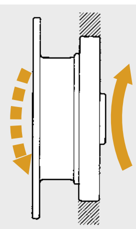
Series: SHG, SHF, SHD

■ Rotational direction

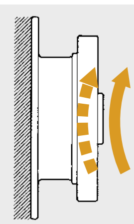
Fig. 010-2

*R indicates the reduction ratio value from the ratings. table

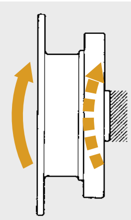
(Note) Contact us if you use the product as an overdrive of (5) or (6).

1


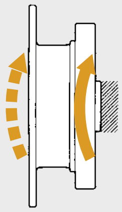
(1) Reducer
Input: Wave Generator
Output: Flexspline
Fixed: Circular Spline
$i=\frac{-1}{R}$

2


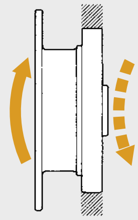
(2) Reducer
Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline
$i=\frac{1}{R+1}$

3


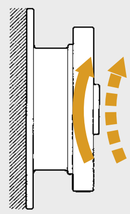
(3) Reducer
Input: Flexspline
Output: Circular Spline
Fixed: Wave Generator
$i=\frac{R}{R+1}$

4


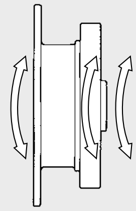
(4) Overdrive
Input: Circular Spline
Output: Flexspline
Fixed: Wave Generator
$i=\frac{R+1}{R}$

5


(5) Overdrive
Input: Flexspline
Output: Wave Generator
Fixed: Circular Spline
$i=-R$

6


(6) Overdrive
Input: Circular Spline
Output: Wave Generator
Fixed: Flexspline
$i=R+1$

7


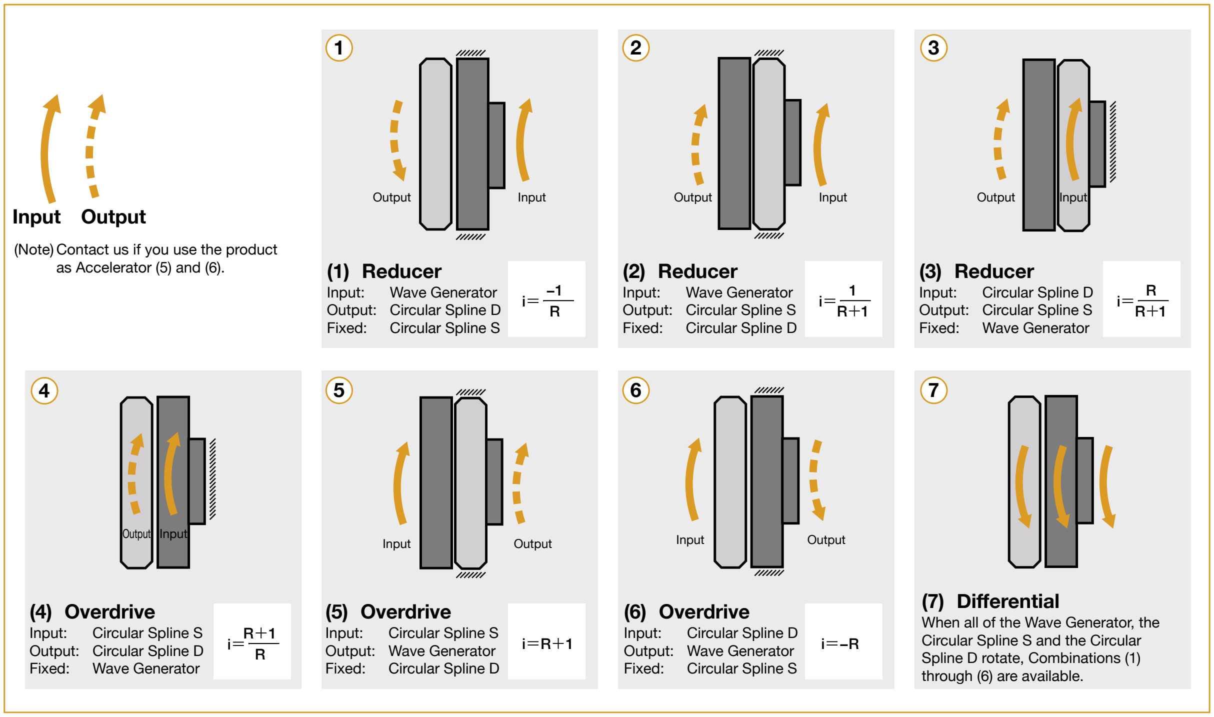
(7) Differential
When all of the wave generator, the flexspline and the circular spline rotate, Combinations (1) through (6) are available.

Pancake

Series: FB and FR

■ Rotational direction

Fig. 11-1



■ Reduction ratio

The reduction ratio is determined by the number of teeth of the Flexspline and the Circular Spline

Number of teeth of the Flexspline: Zf
Number of teeth of the Circular Spline: Zc

▶ Input: Wave Generator
Output: Flexspline
Fixed: Circular Spline

Reduction ratio $i_1 = \frac{1}{R_1} = \frac{Zf-Zc}{Zf}$

▶ Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline

Reduction ratio $i_2 = \frac{1}{R_2} = \frac{Zc-Zf}{Zc}$

■ R_1 indicates the reduction ratio value from the ratings table.

Example

Number of teeth of the Flexspline: 200
Number of teeth of the Circular Spline: 202

▶ Input: Wave Generator
Output: Flexspline
Fixed: Circular Spline

Reduction ratio $i_1 = \frac{1}{R_1} = \frac{200-202}{200} = \frac{-1}{100}$

▶ Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline

Reduction ratio $i_2 = \frac{1}{R_2} = \frac{202-200}{202} = \frac{1}{101}$

Rating Table Definitions

See the corresponding pages of each series for values.

■ Rated torque

Rated torque indicates allowable continuous load torque at rated input speed.

■ Limit for Repeated Peak Torque (see Graph 12-1)

During acceleration and deceleration the Harmonic Drive® gear experiences a peak torque as a result of the moment of inertia of the output load. The table indicates the limit for repeated peak torque.

■ Limit for Average Torque

In cases where load torque and input speed vary, it is necessary to calculate an average value of load torque. The table indicates the limit for average torque. The average torque calculated must not exceed this limit. (calculation formula: Page 14)

■ Limit for Momentary Peak Torque (see Graph 12-1)

The gear may be subjected to momentary peak torques in the event of a collision or emergency stop. The magnitude and frequency of occurrence of such peak torques must be kept to a minimum and they should, under no circumstance, occur during normal operating cycle. The allowable number of occurrences of the momentary peak torque may be calculated by using formula 13-1.

■ Maximum Average Input Speed
Maximum Input Speed

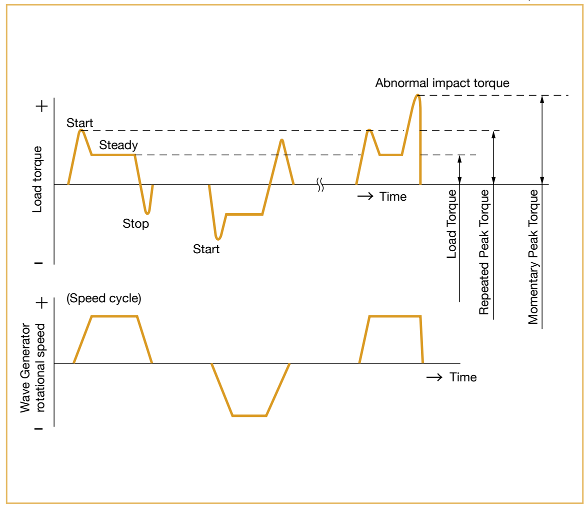
Do not exceed the allowable rating. (calculation formula of the average input speed: Page 14).

■ Moment of Inertia

The rating indicates the moment of inertia reflected to the gear input.

Example of application motion profile

Graph 012-1



Life

■ Life of the wave generator

The life of a gear is determined by the life of the wave generator bearing. The life may be calculated by using the input speed and the output load torque.

Table 012-1

	Life	
Series name	CSF, CSD, SHF, SHD, CSF-mini	CSG, SHG
L_{10}	7,000 hours	10,000 hours
L_{50} (average life)	35,000 hours	50,000 hours

* Life is based on the input speed and output load torque from the rating table.

Calculation formula for Rated Lifetime

Formula 012-1

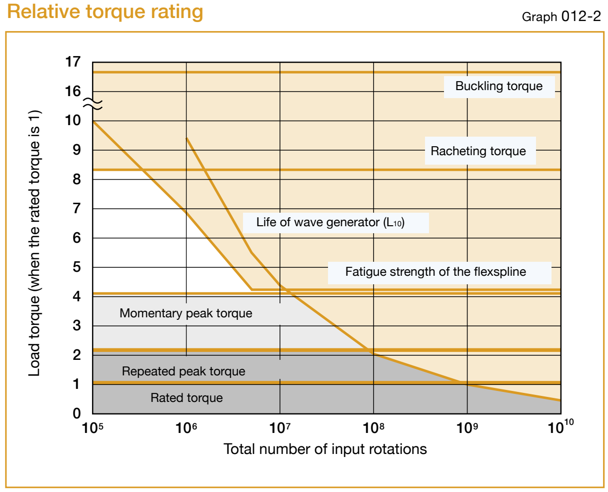
$$L_h = L_n \cdot \left(\frac{T_r}{T_{av}}\right)^3 \cdot \left(\frac{N_r}{N_{av}}\right)$$

Table 012-2

Ln	Life of L_{10} or L_{50}
Tr	Rated torque
Nr	Rated input speed
Tav	Average load torque on the output side (calculation formula: Page 14)
Nav	Average input speed (calculation formula: Page 14)

Relative torque rating

Graph 012-2



* Lubricant life not taken into consideration in the graph described above.
* Use the graph above as reference values.

Torque Limits

■ Strength of flexspline

The Flexspline is subjected to repeated deflections, and its strength determines the torque capacity of the Harmonic Drive® gear. The values given for Rated Torque at Rated Speed and for the allowable Repeated Peak Torque are based on an infinite fatigue life for the Flexspline.
The torque that occurs during a collision must be below the momentary peak torque (impact torque). The maximum number of occurrences is given by the equation below.

Allowable limit of the bending cycles of the flexspline during rotation of the wave generator while the impact torque is applied: 1.0 x 10^4 (cycles)

The torque that occurs during a collision must be below the momentary peak torque (impact torque). The maximum number of occurrences is given by the equation below.

Calculation formula

Formula 013-1

$$N = \frac{1.0\times10^4}{2\times\frac{n}{60}\times t}$$

Allowable occurances	N occurances
Time that impact torque is applied	t sec
Rotational speed of the wave generator	n rpm
The flexspline bends two times per one revolution of the wave generator.	

Caution If the number of occurances is exceeded, the Flexspline may experience a fatigue failure.

■ Buckling torque

When a highly excessive torque (16 to 17 times rated torque) is applied to the output with the input stationary, the flexspline may experience plastic deformation. This is defined as buckling torque.

* See the corresponding pages of each series for buckling torque values.

Warning When the flexspline buckles, early failure of the HarmonicDrive® gear will occur.

■ Ratcheting torque

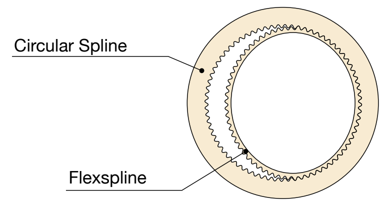
When excessive torque (8 to 9 times rated torque) is applied while the gear is in motion, the teeth between the Circular Spline and Flexspline may not engage properly.
This phenomenon is called ratcheting and the torque at which this occurs is called ratcheting torque. Ratcheting may cause the Flexspline to become non-concentric with the Circular Spline. Operating in this condition may result in shortened life and a Flexspline fatigue failure.

* See the corresponding pages of each series for ratcheting torque values.
* Ratcheting torque is affected by the stiffness of the housing to be used when installing the circular spline. Contact us for details of the ratcheting torque.

Caution When ratcheting occurs, the teeth may not be correctly engaged and become out of alignment as shown in Figure 013-1. Operating the drive in this condition will cause vibration and damage the flexspline.

Caution Once ratcheting occurs, the teeth wear excessively and the ratcheting torque may be lowered.

Figure 013-1



"Dedoidal" condition.

Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

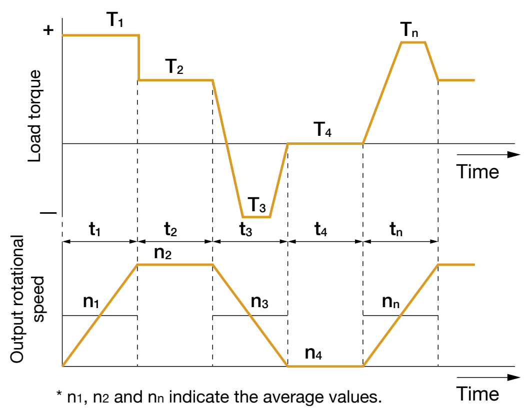
Product Sizing & Selection

In general, a servo system rarely operates at a continuous load and speed. The input rotational speed, load torque change and comparatively large torque are applied at start and stop. Unexpected impact torque may be applied.
These fluctuating load torques should be converted to the average load torque when selecting a model number.
As an accurate cross roller bearing is built in the direct external load support (output flange), the maximum moment load, life of the cross roller bearing and the static safety coefficient should also be checked.

■ Checking the application motion profile

Review the application motion profile. Check the specifications shown in the figure below.

Graph 14-1



* n_1, n_2 and n_n indicate the average values.

Obtain the value of each application motion profile.

Load torque	T_n (Nm)
Time	t_n (sec)
Output rotational speed	n_n (rpm)

Normal operation pattern

Starting (acceleration)	T_1, t_1, n_1
Steady operation (constant velocity)	T_2, t_2, n_2
Stopping (deceleration)	T_3, t_3, n_3
Dwell	T_4, t_4, n_4

Maximum rotational speed

Max. output speed	no ***max***
Max. input rotational speed (Restricted by motors)	ni ***max***

Emergency stop torque

When impact torque is applied	T_s, t_s, n_s

Required life

L_{10} = L (hours)

■ Flowchart for selecting a size

Please use the flowchart shown below for selecting a size. Operating conditions must not exceed the performance ratings.

Calculate the average load torque applied on the output side from the application motion profile: T***av*** (Nm).

$$Tav = \sqrt[3]{\frac{n_1 \cdot t_1 \cdot |T_1|^3 + n_2 \cdot t_2 \cdot |T_2|^3 + \cdots n_n \cdot t_n \cdot |T_n|^3}{n_1 \cdot t_1 + n_2 \cdot t_2 + \cdots n_n \cdot t_n}}$$

↓

Make a preliminary model selection with the following conditions.
T***av*** ≦ Limit for average torque torque
(See the rating table of each series).

↓

Calculate the average output speed: no ***av*** (rpm)

$$no\ av = \frac{n_1 \cdot t_1 + n_2 \cdot t_2 + \cdots n_n \cdot t_n}{t_1 + t_2 + \cdots t_n}$$

Obtain the reduction ratio (R). A limit is placed on "ni ***max***" by motors.

$$\frac{ni\ max}{no\ max} \geqq R$$

Calculate the average input rotational speed from the average output rotational speed (no ***av***) and the reduction ratio (R): ni ***av*** (rpm)

$$ni\ av = no\ av \cdot R$$

Calculate the maximum input rotational speed from the max. output rotational speed (no ***max***) and the reduction ratio (R): ni ***max*** (rpm)

$$ni\ max = no\ max \cdot R$$

↓

Check whether the preliminary model number satisfies the following condition from the rating table.
Ni ***av*** ≦ Limit for average speed (rpm)
Ni ***max*** ≦ Limit for maximum speed (rpm)
→ NG

↓ OK

Check whether T_1 and T_3 are less than the repeated peak torque specification.
→ NG

↓ OK

Check whether T_s is less than the the momentary peak torque specification.
→ NG

↓ OK

Calculate (N_S) the allowable number of rotations during impact torque.

$$N_S = \frac{10^4}{2 \cdot \frac{n_S \cdot R}{60} \cdot t} \quad \cdots\cdots N_S \leqq 1.0 \times 10^4$$

→ NG

↓ OK

Calculate the lifetime.

$$L_{10} = 7000 \cdot \left(\frac{Tr}{Tav}\right)^3 \cdot \left(\frac{nr}{ni\ av}\right) \text{(hours)}$$

Check whether the calculated life is equal to or more than the life of the wave generator (see Page 13).
→ NG

↓ OK

The model number is confirmed.

NG → Review the operation conditions and model number

Example of model number selection

Value of each application motion profile

Load torque	T_n (Nm)
Time	t_n (sec)
Output speed	n_n (rpm)

Normal operation pattern

Starting (acceleration)	T1 = 400 Nm, t1 = 0.3sec, n1 = 7rpm
Steady operation (constant velocity)	T2 = 320 Nm, t2 = 3sec, n2 = 14rpm
Stopping (deceleration)	T3 = 200 Nm, t3 = 0.4sec, n3 = 7rpm
Dwell	T_4 = 0 Nm, t_4 = 0.2 sec, n_4 = 0 rpm

Maximum rotational speed

Max. output speed	no ***max*** = 14 rpm
Max. input speed (Restricted by motors)	ni ***max*** = 1800 rpm

Emergency stop torque

When impact torque is applied	T_s = 500 Nm, t_s = 0.15 sec, n_s = 14 rpm

Required life

	L_{10} = 7000 (hours)

Calculate the average load torque to the output side based on the application motion profile: T***av*** (Nm).

$$T_{av} = \sqrt[3]{\frac{7\,\text{rpm}\cdot 0.3\,\text{sec}\cdot|400\text{Nm}|^3+14\,\text{rpm}\cdot 3\,\text{sec}\cdot|320\text{Nm}|^3+7\,\text{rpm}\cdot 0.4\,\text{sec}\cdot|200\text{Nm}|^3}{7\,\text{rpm}\cdot 0.3\,\text{sec}+14\,\text{rpm}\cdot 3\,\text{sec}+7\,\text{rpm}\cdot 0.4\,\text{sec}}}$$

Make a preliminary model selection with the following conditions. T***av*** = 319 Nm ≦ 451 Nm
(Limit for average torque for model number CSF-40-120-2A-GR: See the rating table on Page 39.)
Thus, **CSF-40-120-2A-GR** is tentatively selected.

Calculate the average output rotational speed: no ***av*** (rpm)

$$n_{o\,av} = \frac{7\,\text{rpm}\cdot 0.3\,\text{sec}+14\,\text{rpm}\cdot 3\,\text{sec}+7\,\text{rpm}\cdot 0.4\,\text{sec}}{0.3\,\text{sec} + 3\,\text{sec} + 0.4\,\text{sec} + 0.2\,\text{sec}} = 12\,\text{rpm}$$

Obtain the reduction ratio (R).

$$\frac{1800\,\text{rpm}}{14\,\text{rpm}} = 128.6 \geqq 120$$

Calculate the average input rotational speed from the average output rotational speed (no ***av***) and the reduction ratio (R): ni ***av*** (rpm)

ni ***av*** = 12 rpm·120 = 1440 rpm

Calculate the maximum input rotational speed from the maximum output rotational speed (no ***max***) and the reduction ratio (R): ni ***max*** (rpm)

ni ***max*** = 14 rpm·120 = 1680 rpm

Check whether the preliminary selected model number satisfies the following condition from the rating table.

Ni ***av*** = 1440 rpm ≦ 3600 rpm (Max average input speed of size 40)
Ni ***max*** = 1680 rpm ≦ 5600 rpm (Max input speed of size 40)

NG / OK

Check whether T_1 and T_3 are equal to or less than the repeated peak torque specification.

T_1 = 400 Nm ≦ 617 Nm (Limit of repeated peak torque of size 40)
T_3 = 200 Nm ≦ 617 Nm (Limit of repeated peak torque of size 40)

NG / OK

Check whether T_s is equal to or less than the momentary peak torque specification.

T_s = 500 Nm ≦ 1180 Nm (Limit for momentary torque of size 40)

NG / OK

Calculate the allowable number (Ns) rotation during impact torque and confirm ≦ 1.0×10⁴

$$N_S = \frac{10^4}{2\cdot\dfrac{14\,\text{rpm}\cdot 120}{60}\cdot 0.15\,\text{sec}} = 1190 \leqq 1.0\times10^4$$

NG / OK

Calculate the lifetime.

$$L_{10} = 7000\cdot\left(\frac{294\ \text{Nm}}{319\ \text{Nm}}\right)^3\cdot\left(\frac{2000\,\text{rpm}}{1440\,\text{rpm}}\right)\text{(hours)}$$

Check whether the calculated life is equal to or more than the life of the wave generator (see Page 12).
L_{10} =7610 hours ≧ 7000 (life of the wave generator: L_{10})

NG / OK

The selection of model number **CSF-40-120-2A-GR** is confirmed from the above calculations.

NG → Review the operation conditions, size and reduction ratio

Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

Lubrication

Component Sets: CSD-2A, CSF-2A, CSG-2A, FB-2, FB-0, FR-2, SHF-2A, SHG-2A and SHD and SHG/SHF -2SO and -2SH gear units: Grease lubricant and oil lubricant are available for lubricating the component sets and SHD gear unit. It is extremely important to properly grease your component sets and SHD gear unit. Proper lubrication is essential for high performance and reliability. Harmonic Drive® component sets are shipped with a rust- preventative oil. The characteristics of the lubricating grease and oil types approved by Harmonic Drive are not changed by mixing with the preservation oil. It is therefore not necessary to remove the preservation oil completely from the gear components. However, the mating surfaces must be degreased before the assembly.

Gear Units: CSG/CSF 2UH and 2UH-LW; CSD-2UF and -2UH; SHG/SHF-2UH and 2UH- LW; SHG/SHF-2UJ; CSF Supermini, CSF Mini, and CSF-2UP.
Grease lubricant is standard for lubricating the gear units. You do not need to apply grease during assembly as the product is lubricated and shipped.
See Page 19 for using lubricant beyond the temperature range in table 16-2.

* Contact us if you want consistency zero (NLGI No.0) for maintenance reasons.

Name of lubricant

Table 016-1

Grease	Harmonic Grease® SK-1A
	Harmonic Grease® SK-2
	Harmonic Grease® 4B No.2
Oil	Industrial gear oil class-2 (extreme pressure) ISO VG68

Temperature

Table 016-2

Grease	SK-1A 0°C to + 40°C
	SK-2 0°C to + 40°C
	4B No.2 –10°C to + 70°C
Oil	ISO VG68 0°C to + 40°C

* The hottest section should not be more than 40° above the ambient temperature.

Note: The three basic components of the gear - the Flexspline, Wave Generator and Circular Spline - are matched and serialized in the factory. Depending on the product they are either greased or prepared with preservation oil. Then the individual components are assembled. If you receive several units, please be careful not to mix the matched components. This can be avoided by verifying that the serial numbers of the assembled gear components are identical.

Grease lubricant

■ Types of lubricant

Harmonic Grease® SK-1A

This grease was developed for Harmonic Drive® gears and features good durability and efficiency.

Harmonic Grease® SK-2

This grease was developed for small sized Harmonic Drive® gears and features smooth rotation of the Wave Generator since high pressure additive is liquefied.

Harmonic Grease® 4B No.2

This has been developed exclusively for the CSF and CSG and features long life and can be used over a wide range of temperature.

(Note)

1. Grease lubrication must have proper sealing, this is essential for 4B No.2.
   Rotating part: Oil seal with spring is needed.
   Mating part: O ring or seal adhesive is needed.

2. The grease has the highest deterioration rate in the region where the grease is subjected to the greatest shear (near wave generator).
   Its viscosity is between JIS No.0 and No.00 depending on the operation.

Table 016-3

NLGI consistency No.	Mixing consistency range
0	355 to 385
00	400 to 430

Grease specification

Table 016-4

Grease	SK-1A	SK-2	4B No.2
Base oil	Refined oil	Refined oil	Composite hydrocarbon oil
Base Viscosity cSt (25°C)	265 to 295	265 to 295	290 to 320
Thickening agent	Lithium soap base	Lithium soap base	Urea
NLGI consistency No.	No. 2	No. 2	No. 1.5
Additive	Extreme-pressure additive, others	Extreme-pressure additive, others	Extreme-pressure additive, others
Drop Point	197°C	198°C	247°C
Appearance	Yellow	Green	Light yellow
Storage life	5 years in sealed condition	5 years in sealed condition	5 years in sealed condition

■ Compatible grease by size

Compatible grease varies depending on the size and reduction ratio. See the following compatibility table. We recommend SK-1A and SK-2 for general use.

Ratios 30:1

Table 016-5

Size	8	11	14	17	20	25	32
SK-1A	–	–	–	–	○	○	○
SK-2	○	○	○	○	–	–	–
4B No.2	△	△	△	△	□	□	□

Ratios 50:1* and above

Table 016-6

Size	8	11	14	17	20	25	32
SK-1A	–	–	–	–	○	○	○
SK-2	○	○	○	○	△	△	△
4B No.2	–	–	□	□	□	□	□

Size	40	45	50	58	65	80	90	100
SK-1A	○	○	○	○	○	○	○	○
SK-2	△	–	–	–	–	–	–	–
4B No.2	□	□	□	□	□	□	□	□

○: Standard grease
△: Semi-standard grease
□: Recommended grease for long life and high load

*** Oil lubrication is required for component-sets size 50 or larger with a reduction ratio of 50:1.**

Grease characteristics

Table 016-7

Grease	SK-1A	SK-2	4B No.2
Durability	○	○	◎
Fretting resistance	○	○	◎
Low-temperature performance	△	△	◎
Grease leakage	◎	◎	△

Excellent :◎
Good :○
Use Caution :△

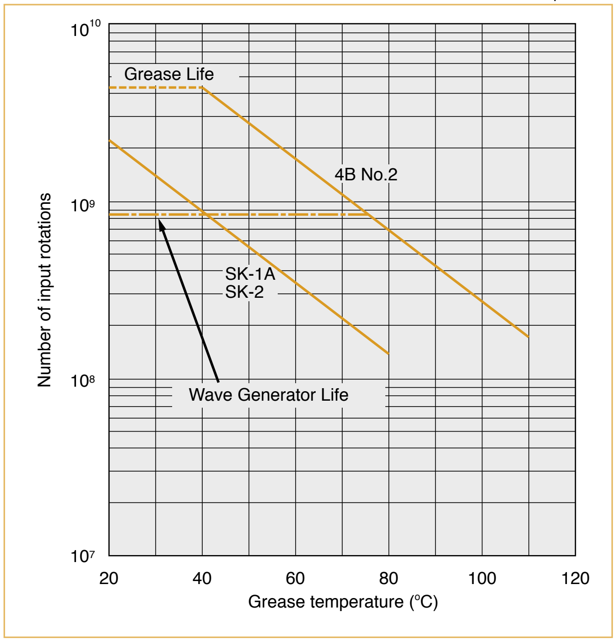
■ When to replace grease

The wear characteristics of the gear are strongly influenced by the condition of the grease lubrication. The condition of the grease is affected by the ambient temperature. The graph 017-1 shows the maximum number of input rotations for various temperatures. This graph applies to applications where the average load torque does not exceed the rated torque.

Note: Recommended Grease: SK-1A or SK-2

When to replace grease: L_{GTn} (when the average load torque is equal to or less than the rated torque)

Graph 017-1



Calculation formula when the average load torque exceeds the rated torque

Formula 017-1

$$L_{GT} = L_{GTn} \times \left(\frac{Tr}{Tav}\right)^3$$

Formula Symbols

Table 017-1

L_{GT}	Grease change (if average load torque exceeds rated torque)	input revolutions	————
L_{GTn}	Grease change (if average load torque is equal to or less than rated torque)	input revolutions (From Graph)	See the Graph 017-1.
Tr	Rated torque	Nm	See the "Ratings Table" of each series.
Tav	Average load torque	Nm	Calculation formula: See Page 014.

■ Other precautions

1. Avoid mixing different kinds of grease. The gear should be in an individual case when installed.

2. Please contact us when you use HarmonicDrive® gears at constant load or in one direction continuously, as it may cause lubrication problems.

3. Grease leakage. A sealed structure is needed to maintain the high durability of the gear and prevent grease leakage.

■ See the corresponding pages of the design guide of each series for “Recommended minimum housing clearance,” Application guide” and “Application quantity.”

Precautions on using Harmonic Grease® 4B No.2

Harmonic Grease® 4B No.2 lubrication is ideally suited for Harmonic Drive® gears.

(1) Apply the grease to each contacting joint at the beginning of operation.
(2) Remove any contaminents created by abrasion during running-in period.

■ See the corresponding pages of the design guide of each series for “recommended minimum housing clearance,” Application guide” and “Application quantity.”

■ Precautions

(1) Stir Grease
When storing Harmonic Grease 4B No.2 lubrication in the container, it is common for the oil to weep from the thickener. Before greasing, stir the grease in the container to mix and soften.

(2) Aging (running-in)
The aging before the main operation softens the applied grease. More effective greasing performance can be realized when the grease is distributed around each contact surface.
Therefore, the following aging methods are recommended.

- Keep the internal temperature at 80ºC or cooler. Do not start the aging at high temperature rapidly.
- Input rotational speed should be 1000rpm to 3000rpm. However, the lower rotational speed of 1000rpm is more effective. Set the speed as low as possible within the indicated range.
- The time required for aging is 20 minutes or longer.
- Operation range for aging: Keep the output rotational angle as large as possible.

Contact us if you have any questions for handling Harmonic Grease 4B No.2 lubrication.

Note: Strict sealing is required to prevent grease leakage.

Oil lubricant

■ Types of oil

The specified standard lubricant is “Industrial gear oil class-2 (extreme pressure) ISO VG68.”
We recommend the following brands as a commercial lubricant.

Table 018-1

Standard	Mobil Oil	Exxon	Shell	COSMO Oil	Japan Energy	NIPPON Oil	Idemitsu Kosan	General Oil	Klüber
Industrial gear oil class-2 (extreme pressure) ISO VG68	Mobilgear 600XP68	Spartan EP68	Omala Oil 68	Cosmo gear SE68	ES gear G68	Bonock M68, Bonock AX68	Daphne super gear LW68	General Oil SP gear roll 68	Syntheso D-68EP

■ When to replace oil

First time ························ 100 hours after starting operation
Second time or after ······· Every 1000 operation hours or every 6 months
Note that you should replace the oil earlier than specified if the operating condition is demanding.

■ See the corresponding pages of the design guide of each series for specific details.

■ Other precautions

1. Avoid mixing different kinds of oil. The gear should be in an individual case when installed.

2. When you use size 50 or above at max allowable input speed, please contact us as it may cause lubrication problems.

*** Oil lubrication is required for component-sets size 50 or larger with a reduction ratio of 50:1.**

Lubricant for special environments

When the ambient temperature is special (other than the "temperature range of the operating environment" on Page 016-2), you should select a lubricant appropriate for the operating temperature range.

Harmonic Grease 4B No.2

Table 019-1

Type of lubricant	Operating temperature range	Available temperature range
Grease	−10℃ to + 110℃	−50℃ to + 130℃

High temperature lubricant

Table 019-2

Type of lubricant	Lubricant and manufacturer	Available temperature range
Grease	Mobil grease 28: Mobil Oil	−5℃ to + 160℃
Oil	Mobil SHC-626: Mobil Oil	−5℃ to + 140℃

Low temperature lubricant

Table 019-3

Type of lubricant	Lubricant and manufacturer	Available temperature range
Grease	Multemp SH-KII: Kyodo Oil	−30℃ to + 50℃
	Isoflex LDS-18 special A: KLÜBER	−25℃ to + 80℃
Oil	SH-200-100CS: Toray Silicon	−40℃ to + 140℃
	Syntheso D-32EP: KLÜBER	−25℃ to + 90℃

Harmonic Grease 4B No.2

The operating temperature range of Harmonic Grease 4B No.2 lubrication is the temperature at the lubricating section with the performance and characteristics of the gear taken into consideration. (It is not ambient temperature.)

As the available temperature range indicates the temperature of the independent lubricant, restriction is added on operating conditions (such as load torque, rotational speed and operating cycle) of the gear. When the ambient temperature is very high or low, materials of the parts of the gear need to be reviewed for suitability. Contact us if operating in high temperature.

Harmonic Grease 4B No.2 can be used in the available temperature range shown in table 019-1. However, input running torque will increase at low temperatures, and grease life will be decreased at high temperatures due to oxidation and lubricant degradation.

Torsional Stiffness

Stiffness and backlash of the drive system greatly affects the performance of the servo system. Please perform a detailed review of these items before designing your equipment and selecting a model number.

■ Stiffness

Fixing the input side (wave generator) and applying torque to the output side (flexspline) generates a torsional angle almost proportional to the torque on the output side. Figure 020-1 shows the torsional angle at the output side when the torque applied on the output side starts from zero, increases up to $+T_0$ and decreases down to $-T_0$. This is called the “Torque – torsion angle diagram,” which normally draws a loop of 0 – A – B – A′ – B′ – A. The slope described in the “Torque – torsion angle diagram” is represented as the spring constant for the stiffness of the HarmonicDrive® gear (unit: Nm/rad).
As shown in Figure 020-2 “Spring Constant Diagram” is divided into 3 regions, and the spring constants in the area are represented by K_1, K_2 and K_3.

K_1 ···· The spring constant when the torque changes from [zero] to [T_1]
K_2 ···· The spring constant when the torque changes from [T_1] to [T_2]
K_3 ···· The spring constant when the torque changes from [T_2] to [T_3]

■ See the corresponding pages of each series for values of the spring constants (K_1, K_2, K_3) and the torque-torsional angles (T_1, T_2, - θ_1, θ_2).

■ Example for calculating the torsion angle

The torsion angle (θ) is calculated here using CSF-25-100-2A-GR as an example.

When the applied torque is T_1 or less, the torsion angle θ_{L1} is calculated as follows:
When the load torque T_{L1}=2.9 Nm

$\theta_{L1} = T_{L1}/K_1$
$= 2.9/3.1\times10^4$
$= 9.4\times10^{-5}$ rad (0.33 arc min)

When the applied torque is between T_1 and T_2, the torsion angle θ_{L2} is calculated as follows:
When the load torque is T_{L2}=39 Nm

$\theta_{L2} = \theta_1 + (T_{L2} - T_1)/K_2$
$= 4.4\times10^{-4} + (39-14)/5.0\times10^4$
$= 9.4\times10^{-4}$ rad (3.2 arc min)

When a bidirectional load is applied, the total torsion angle will be 2 x θ_{LX} plus hysteresis loss.

* The torsion angle calculation is for the gear component set only and does not include any torsional windup of the output shaft.

Note: See p.120 for torsional stiffness for pancake gearing .

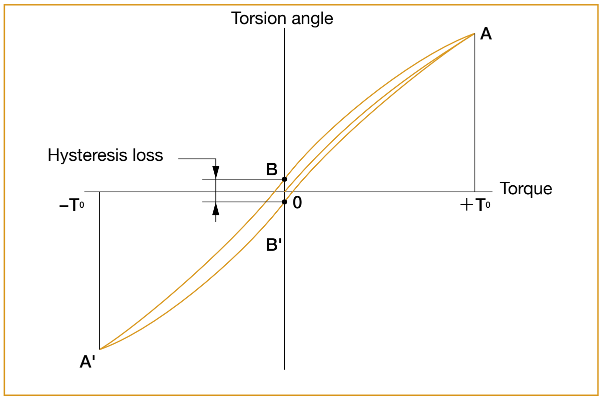
■ Hysteresis loss (Silk hat and cup style only)

As shown in Figure 020-1, when the applied torque is increased to the rated torque and is brought back to [zero], the torsional angle does not return exactly back to the zero point This small difference (B – B') is called hysteresis loss.

■ See the corresponding page of each series for the hysteresis loss value.

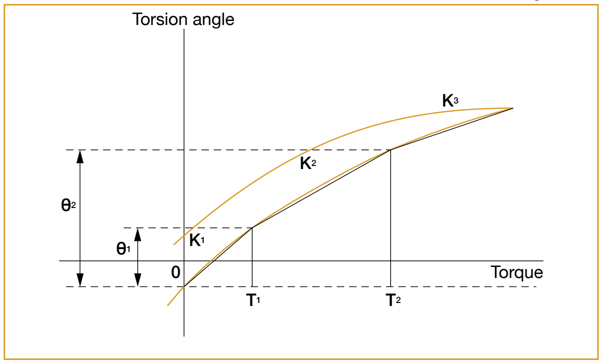
Torque - torsion angle diagram

Figure 020-1



Spring constant diagram

Figure 020-2



■ Backlash (Silk hat and cup style only)

Hysteresis loss is primarily caused by internal friction. It is a very small value and will vary roughly in proportion to the applied load. Because HarmonicDrive® gears have zero backlash, the only true backlash is due to the clearance in the Oldham coupling, a self-aligning mechanism used on the wave generator. Since the Oldham coupling is used on the input, the backlash measured at the output is extremely small (arc-seconds) since it is divided by the gear reduction ratio.

Positional Accuracy

Positional Accuracy values represent the difference between the theoretical angle and the actual angle of output for any given input. The values shown in the table are maximum values.

- See the corresponding pages of each series for transmission accuracy values.

Example of measurement

Graph 021-1

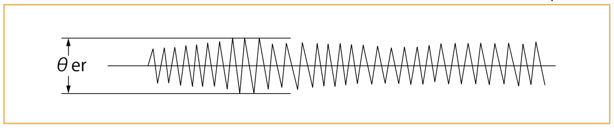


Table 021-1

θ_{er}	Transmission accuracy
θ_1	Input angle
θ_2	Actual output angle
R	Reduction ratio

Formula 021-1

$$\theta_{er} = \theta_2 - \frac{\theta_1}{R}$$

Vibration

The primary frequency of the transmission error of the HarmonicDrive® gear may cause a vibration of the load inertia. This can occur when the driving frequency of the servo system including the HarmonicDrive® gear is at, or close to the resonant frequency of the system. Refer to the design guide of each series.

The primary component of the transmission error occurs twice per input revolution of the input. Therefore, the frequency generated by the transmission error is 2x the input frequency (rev / sec).

If the resonant frequency of the entire system, including the HarmonicDrive® gear, is F=15 Hz, then the input speed (N) which would generate that frequency could be calculated with the formula below.

Formula 021-2

$$N = \frac{15}{2} \cdot 60 = 450 \text{ rpm}$$

The resonant frequency is generated at an input speed of 450 rpm.

How to the calculate resonant frequency of the system

Formula 021-3

$$f = \frac{1}{2\pi} \sqrt{\frac{K}{J}}$$

Formula variables

Table 021-2

f	The resonant frequency of the system	Hz	
K	Spring constant	Nm/rad	See pages of each series
J	Load inertia	kgm^2	

Starting Torque

Starting torque is the torque value applied to the input side at which the output first starts to rotate. The values in the table of each series indicate the maximum value, and the lower-limit value indicates approximately $^1/_2$ to $^1/_3$ of the maximum value.

Measurement conditions:
No-load, ambient temperature: +20ºC

■ See the corresponding pages of each series for starting torque values.

* Use the values in the table of each series as reference values as they vary depending on the usage conditions.

Backdriving Torque

Backdriving torque is the torque value applied to the output side at which the input first starts to rotate. The values in the table are maximum values, typical values are approximately $^1/_2$ of the maximum values.
Note: Never rely on these values as a margin in a system that must hold an external load. A brake must be used where back driving is not permissible.

Measurement conditions:
No-load, ambient temperature: +20ºC

■ See the corresponding pages of each series for backdriving torque values.

* Use the values in the table of each series as reference values as they vary depending on the usage conditions.

No-Load Running Torque

No-load running torque is the torque which is required to rotate the input side (high speed side), when there is no load on the output side (low speed side). The graph of the no-load running torque shown in this catalog depends on the measurement conditions shown in Table 023-1.
Add the compensation values shown by each series to all reduction ratios except 100:1.

■ See the corresponding pages of each series for no-load running torque values.

Measurement condition

Table 023-1

Reduction ratio 100			
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A
			Harmonic Grease SK-2
		Quantity	(See pages of each series)
Torque value is measured after 2 hours at 2000 rpm input			

* Contact us for oil lubrication.

Efficiency

The efficiency varies depending on the following conditions.

- Reduction ratio
- Input speed
- Load torque
- Temperature
- Lubrication (type and quantity)

The efficiency characteristics of each series shown in this catalog depends on the measurement condition shown in Table 023-2.

■ See the corresponding pages of each series for efficiency values.

Measurement condition

Table 023-2

Installation	Based on recommended tolerance		
Load torque	The rated torque shown in the rating table (see the corresponding pages on each series)		
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A
			Harmonic Grease SK-2
		Quantity	Recommended quantity (see the pages on each series)

* Contact us for oil lubrication.

■ Efficiency compensation coefficient

If load torque is below rated torque, a compensation factor must be employed. Calculate the compensation coefficient Ke from the efficiency compensation coefficient graph of each series and use the following example for calculation.

Example of calculation

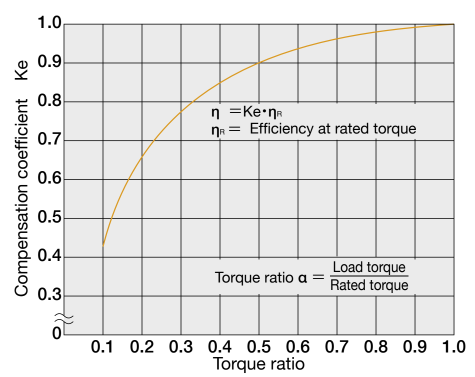
Efficiency **η** (%) under the following condition is obtained from the example of CSF-20-80-2A-GR.
Input rotational speed: 1000 rpm
Load torque: 19.6 Nm
Lubrication method: Grease lubrication (Harmonic Grease SK-1A)
Lubricant temperature: 20°C
Since the rated torque of size 20 with a reduction ratio of 80 is 34 Nm (Ratings: Page 039), the torque ratio **α** is 0.58.
(**α**=19.6/34=0.58)

■ The efficiency compensation coefficient is Ke=0.93 from Graph 023-1.

■ Efficiency **η** at load torque 19.6 Nm: **η**=Ke•**η**R=0.93 x 78=73%

Efficiency compensation coefficient (CSF series)

Graph 023-1



* Efficiency compensation coefficient Ke=1 when the load torque is greater than the rated torque.

Design Guidelines

Design guideline

The relative perpendicularity and concentricity of the three basic Harmonic Drive® elements have an important influence on accuracy and service life.

Misalignments will adversely affect performance and reliability. Compliance with recommended assembly tolerances is essential in order for the advantages of Harmonic Drive® gearing to be fully realized. Please consider the following when designing:

(1) Input shaft, Circular Spline and housing must be concentric.

(2) When operating, an axial force is generated on the wave generator. Input bearings must be selected to accommodate this axial load. See page 27.

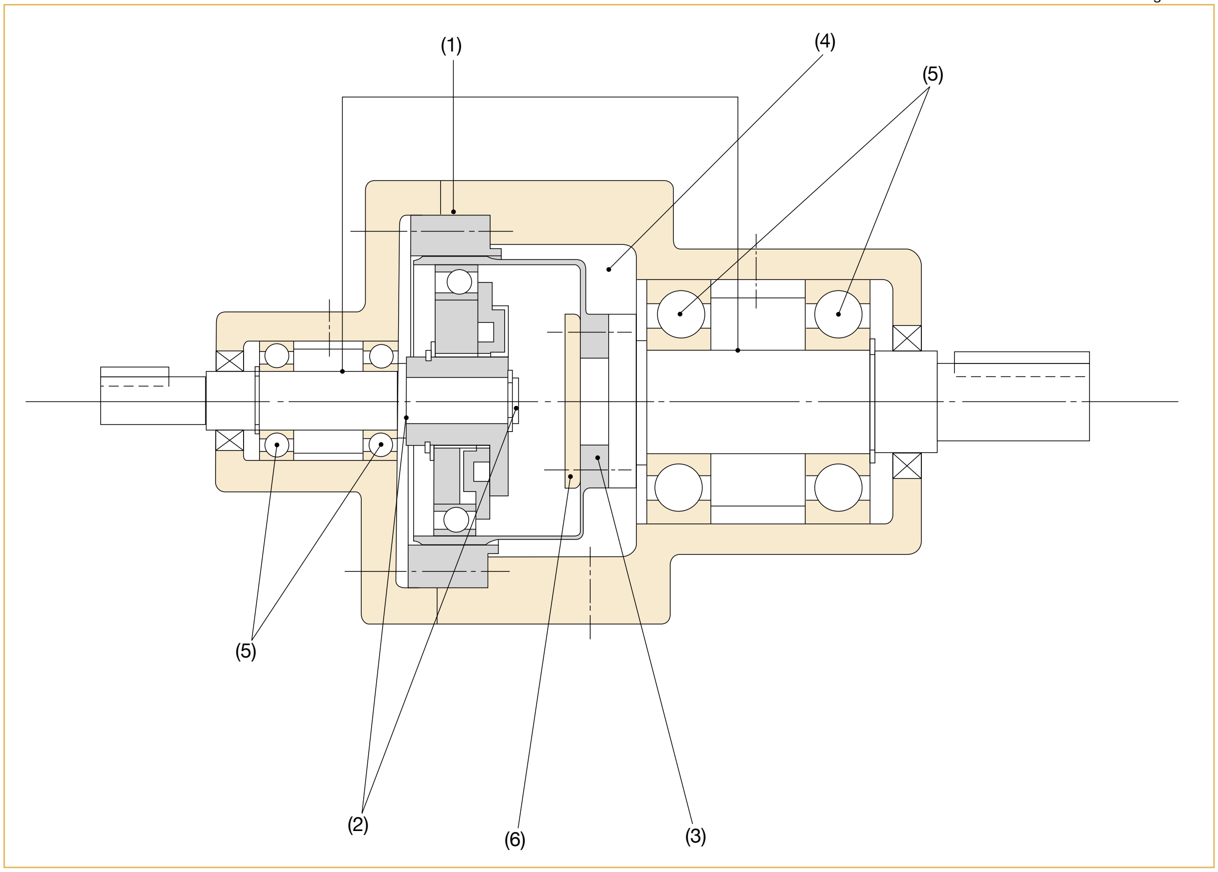
(3) Even though a HarmonicDrive® gear is compact, it transmits large torques. Therefore, assure that all required bolts are used to fasten the circular spline and flexspline and that they are tightened to the recommended torque.

(4) As the flexspline is subject to elastic deformation, the A minimal clearance between the flexspline and housing is required. Refer to "Minimum Housing Clearance" on the drawing dimension tables.

(5) The input shaft and output shaft are supported by anti-friction bearings. As the wave generator and flexspline elements are meant to transmit pure torque only, the bearing arrangement needs to isolate the harmonic gearing from external forces applied to either shaft. A common bearing arrangement is depicted in the diagram.

(6) A clamping plate is recommended (item 6). Its purpose is to spread fastening forces and to avoid any chance of making physical contact with the thin section of the flexspline diaphragm. The clamping plate shall not exceed the diaphragm's boss diameter and is to be designed in accordance with catalog recommendations.

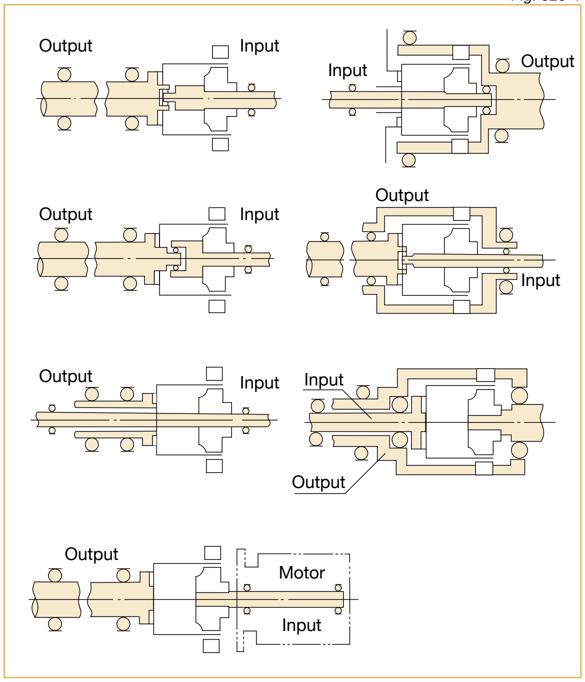
Fig. 024-1



Bearing support for the input and output shafts

For the component sets, both input and output shafts must be supported by two adequately spaced bearings in order to withstand external radial and axial forces without excessive deflection.
In order to avoid damage to the component set when limited external loads are anticipated, both input and output shafts must be axially fixed.
Bearings must be selected whose radial play does not exceed ISO-standard C 2 class or "normal" class. The bearings should be axially and radially preloaded to eliminate backlash.
Examples of correct bearing arrangements are shown in fig 025-1.

Fig. 025-1

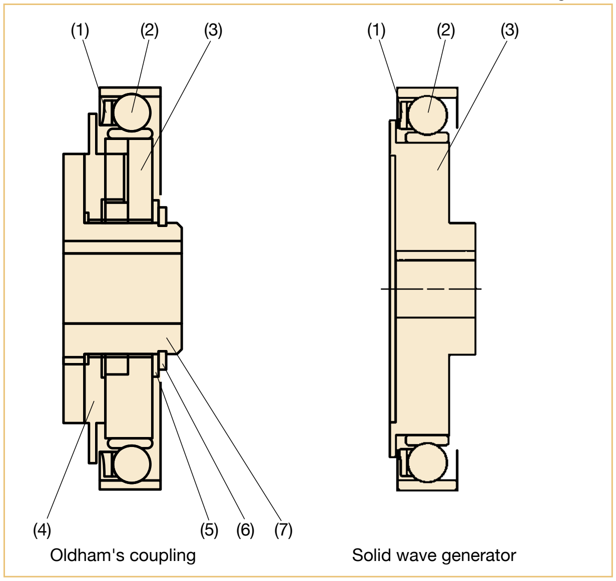


Wave generator

■ Structure of the wave generator

The wave generator includes an Oldham's coupling type with a self-aligning structure and an integrated solid wave generator without a self-aligning structure, and which is used depends on the series.
See the diagram of each series for details. The basic structure of the wave generator and the shape are shown below.

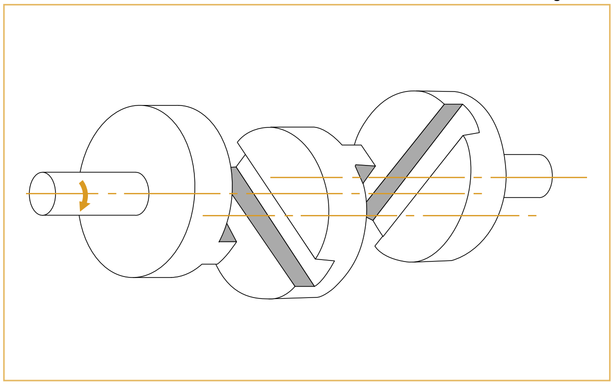
Fig. 026-1



(1) Ball Separator
(2) Wave generator bearing
(3) Wave generator plug
(4) Insert
(5) Rubwasher
(6) Snap ring
(7) Wave generator hub

Structure of Oldham's coupling

Fig. 026-2



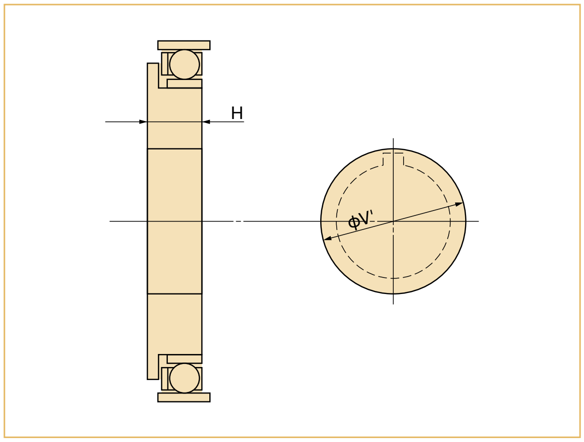
■ Maximum hole diameter of wave generator

The standard hole dimension of the wave generator is shown for each size. The dimension can be changed within a range up to the maximum hole dimension. We recommend the dimension of keyway based on JIS standard. It is necessary that the dimension of keyways should sustain the transmission torque.

* Tapered holes are also available.

In cases where a larger hole is required, use the wave generator without the Oldham coupling. The maximum diameter of the hole should be considered to prevent deformation of the Wave Generator plug by load torque. The dimension is shown in the table below and includes the dimension of depth of keyway.
(This is the value including the dimension of the depth of keyway.)

Hole diameter of the wave generator — Fig. 027-1



Hole diameter of the wave generator hub with Oldham coupling — Table 027-1, Unit: mm

Size	8	11	14	17	20	25	32	40	45	50	58	65	80	90	100
Standard dim. (H7)	3	5	6	8	9	11	14	14	19	19	22	24	28	28	28
Minimum hole dim.	—	—	3	4	5	6	6	10	10	10	13	16	16	19	22
Maximum hole dim.	—	—	8	10	13	15	15	20	20	20	25	30	35	37	40

Maximum hole diameter without Oldham Coupling — Table 027-2, Unit: mm

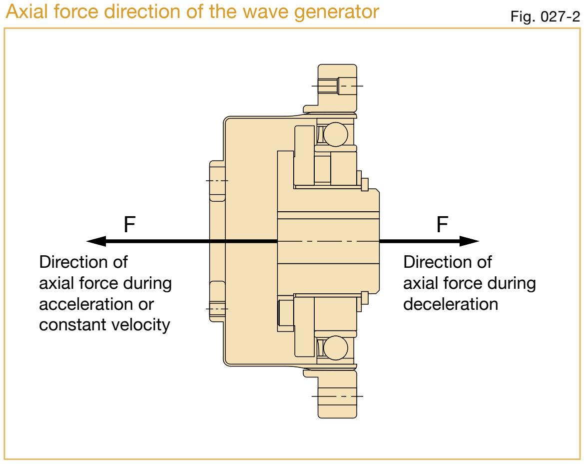
Size	8	11	14	17	20	25	32	40	45	50	58	65	80	90	100
Max. hole dia.ΦV'	10	14	17	20	23	28	36	42	47	52	60	67	72	84	95
Min. plug thick.$H^{0}_{-0.1}$	5.7	6.7	7.2	7.6	11.3	11.3	13.7	15.9	17.8	19	21.4	23.5	28.5	31.3	34.9

■ Axial Force of Wave Generator

When the gear is used to accelerate a load, the deflection of the Flexspline leads to an axial force acting on the Wave Generator. This axial force, which acts in the direction of the closed end of the Flexspline, must be supported by the bearings of the input shaft (motor shaft). When the gear is used to decelerate a load, an axial force acts to push the Wave Generator out of the Flexspline cup. Maximum axial force of the Wave Generator can be calculated by the equation shown below. The axial force may vary depending on its operating condition. The value of axial force tends to be a larger number when using high torque, extreme low speed and constant operation. The force is calculated (approximately) by the equation. In all cases, the Wave Generator must be axially (in both directions), as well as torsionally, fixed to the input shaft.

(Note)
Please contact us for further information on attaching the Wave Generator to the input (motor) shaft.

Axial force direction of the wave generator — Fig. 027-2



Formula for Axial Force — Table 027-3

Reduction ratio	Calculation formula
30	$F=2\times\frac{T}{D}\times0.07\times\tan 32°$
50	$F=2\times\frac{T}{D}\times0.07\times\tan 30°$
80 or more	$F=2\times\frac{T}{D}\times0.07\times\tan 20°$

Symbols for Formula — Table 027-4

F	Axial force	N	See Figure 027-2
D	Size	m	
T	Output torque	Nm	

Calculation example — Formula 027-1

Model name: CSF series
Size: 32
Reduction ratio: 50
Output torque: 382 Nm
(maximum allowable momentary torque)

$$F=2\times\frac{382}{(32\times0.00254)}\times0.07\times\tan 30°$$

$$F=380N$$

Assembly Precautions

Sealing

Sealing is needed to maintain the high durability of the gear and prevent grease leakage. Recommended for all mating surfaces, if the o-ring is not used. Flanges provided with o-ring grooves must be sealed when a proper seal cannot be achieved using the o-ring alone.

- Rotating Parts .... Oil seal with spring is needed.
- Mating flange .... O-ring or seal adhesive is needed.
- Screw hole area .... Screws should have a thread lock (LOCTITE® 242 is recommended) or seal adhesive.

(Note) If you use Harmonic Grease 4BNo.2, strict sealing is required.

Sealing recommendations for gear units

Table 028-1

Area requiring sealing		Recommended sealing method
Output side	Holes which penetrate housing	Use O-ring (supplied with the product)
	Installation screw / bolt	Screw lock adhesive which has effective seal (LOCTITE® 242 is recommended)
Input side	Flange surfaces	Use O-ring (supplied with the product)
	Motor output shaft	Please select a motor which has an oil seal on the output shaft.

Assembly precautions

The wave generator is installed after the flexspline and circular spline. If the wave generator is not inserted into the flexspline last, gear teeth scuffing damage or improper eccentric gear mesh may result. Installation resulting in an eccentric tooth mesh (Dedoidal) will cause noise and vibration, and can lead to early failure of the gear. For proper function, the teeth of the flexspline and Circular Spline mesh symmetrically.

■ Precautions on the wave generator

1. Avoid applying undue axial force to the wave generator during installation. Rotating the wave generator bearing while inserting it is recommended and will ease the process.
2. If the wave generator does not have an Oldham coupling, extra care must be given to ensure that concentricity and inclination are within the specified limits

■ Precautions on the circular spline

The circular Spline must not be deformed in any way during the assembly. It is particularly important that the mounting surfaces are prepared correctly

1. Mounting surfaces need to have adequate flatness, smoothness, and no distortion.
2. Especially in the area of the screw holes, burrs or foreign matter should not be present.
3. Adequate relief in the housing corners is needed to prevent interference with the corner of the circular spline.
4. The circular spline should be rotatable within the housing. Be sure there is not interference and that it does not catch on anything.
5. When a bolt is inserted into a bolt hole during installation, make sure that the bolt fits securely and is not in an improper position or inclination.
6. Do not apply torque at recommended torque all at once. First, apply torque at about half of the recommended value to all bolts, then tighten at recommended torque. Order of tightening bolts must be diagonal.
7. Avoid pinning the circular spline if possible as it can reduce the rotational precision and smoothness of operation.

■ Precautions on the flexspline

1. Mounting surfaces need to have adequate flatness, smoothness, and no distortion.
2. Especially in the area of the screw holes, burrs or foreign matter should not be present.
3. Adequate clearance with the housing is needed to ensure no interference especially with the major axis of flexspline
4. Bolts should rotate freely when installing through the mounting holes of the flexspline and should not have any irregularity due to the shaft bolt holes being misaligned or oblique.
5. Do not tighten the bolts with the specified torque all at once. Tighten the bolts temporarily with about half the specified torque, and then tighten them to the specified torque. Tighten them in an even, crisscross pattern.
6. The flexspline and circular spline are concentric after assembly. After installing the wave generator bearing, if it rotates in unbalanced way, check the mounting for dedoidal or non-concentric installation.
7. Care should be taken not to damage the flexspline diaphragm or gear teeth during assembly.

   Avoid hitting the tips of the flexpline teeth and circular spline teeth. Avoid installing the CS from the open side of the flexspline after the wave generator has been installed.

■ Rust prevention

Although the Harmonic Drive® gears come with some corrosion protection, the gear can rust if exposed to the environment. The gear external surfaces typically have only a temporary corrosion inhibitor and some oil applied. If an anti-rust product is needed, please contact us to review the options.

"Dedoidal" state

It is normal for the flexspline to engage with the circular spline symmetrically as shown in Figure 029-1. However, if the ratcheting phenomenon, which is described on Page 013, is caused or if the three parts are forcibly inserted and assembled, engagement of the teeth may be out of alignment as shown in Figure 029-2. This is called "dedoidal". Note: Early failure of the gear will occur.

■ How to check "dedoidal"

By performing the following methods, check whether the gear engagement is "dedoidal".

(1) Judging by the irregular torque generated when the wave generator turns

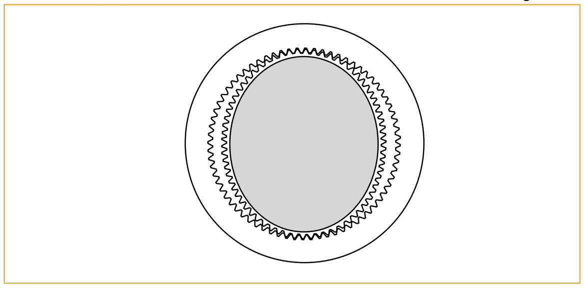
1) Slowly turn the input shaft with your hand in a no-load condition. If you can turn it with average force, it is normal. If it turns irregularly, it may be "dedoidal".

2) Turn the wave generator in a no-load condition if it is attached to a motor. If the average current value of the motor is about 2 to 3 times the normal value, it may be "dedoidal".

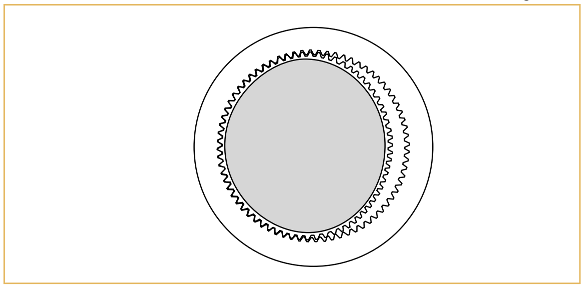
(2) Judging by measuring vibration on the body of the flexspline

The scale deflection of the dial gauge draws a sine wave as shown by the solid line in Graph 029-3 when it is normally assembled. When "dedoidal" occurs, the gauge draws a deflected wave shown by the dotted line as the flexspline is out of alignment.

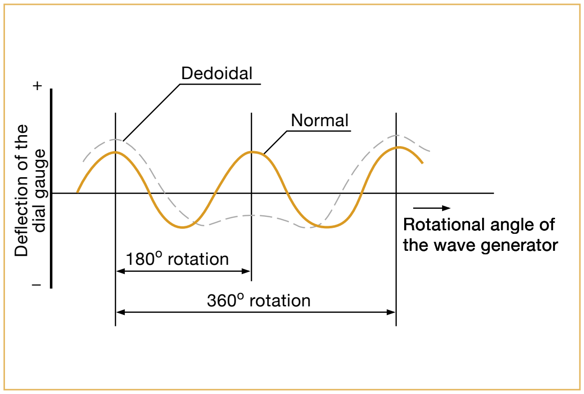
Normal engagement status   Fig. 029-1



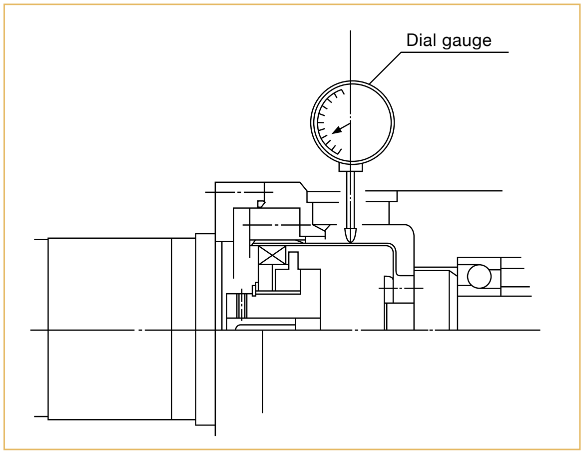
"Dedoidal" status   Fig. 029-2



Deflection of the dial gauge   Graph 029-3



Measuring the deflection on the body of the flexspline   Fig. 029-4



Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

Checking Output Bearing

A precision cross roller bearing is built in the unit type and the gear head type to directly support the external load (output flange) (precision 4-point contact ball bearing for the CSF-mini series).
Please calculate maximum moment load, life of cross roller bearing, and static safety factor to fully maximize the performance of a housed unit (gearhead).

■ See the corresponding pages on each series for cross roller bearing specifications.

Checking procedure

(1) Checking the maximum moment load (M_{max})

Calculate maximum moment load (M_{max}). → Maximum moment load (M_{max}) ≦ allowable moment (Mc)

(2) Checking the life

Calculate the radial load (Fr_{av}) and the average axial load (Fa_{av}). → Calculate the radial load coefficient (x) and the axial load coefficient (y). → Calculate lifetime

(3) Checking the static safety coefficient

Calculate the static equivalent radial load coefficient (Po). → Check the static safety coefficient. (fs)

How to calculate the maximum moment load

Maximum moment load (M_{max}) is obtained as follows.
Make sure that $M_{max} \leqq Mc$.

Formula 030-1

$$M_{max} = Fr_{max}\,(Lr+R) + Fa_{max} \cdot La$$

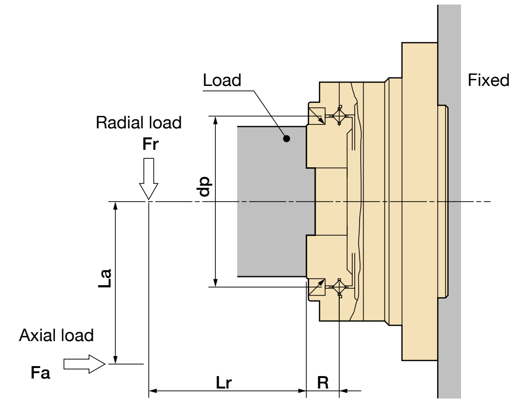
Symbols for Formula 030-1

Table 030-1

Fr_{max}	Max. radial load	N(kgf)	See Fig. 030-1.
Fa_{max}	Max. axial load	N(kgf)	See Fig. 030-1.
Lr, La	————	m	See Fig. 030-1.
R	Offset amount	m	See Fig. 030-1 and "Specification of the output bearing" of each series.

External load influence diagram

Fig. 030-1



How to calculate the average load

(Average radial load, average axial load, average output speed)

When the radial load and axial load vary, the life of cross roller bearing can be determined by converting to an average load.

How to calculate the average radial load (Fr_{av})

Formula 031-1

(Cross roller bearing)

$$Fr_{av} = \sqrt[10/3]{\frac{n_1t_1(|Fr_1|)^{10/3} + n_2t_2(|Fr_2|)^{10/3} \cdots + n_nt_n(|Fr_n|)^{10/3}}{n_1t_1 + n_2t_2 \cdots + n_nt_n}}$$

(4-point contact ball bearing)

$$Fr_{av} = \sqrt[3]{\frac{n_1t_1(|Fr_1|)^{3} + n_2t_2(|Fr_2|)^{3} \cdots + n_nt_n(|Fr_n|)^{3}}{n_1t_1 + n_2t_2 \cdots + n_nt_n}}$$

Note that the maximum radial load in t_1 is Fr_1 and the maximum radial load in t_3 is Fr_3.

How to calculate the average axial load (Fa_{av})

Formula 031-2

(Cross roller bearing)

$$Fa_{av} = \sqrt[10/3]{\frac{n_1t_1(|Fa_1|)^{10/3} + n_2t_2(|Fa_2|)^{10/3} \cdots + n_nt_n(|Fa_n|)^{10/3}}{n_1t_1 + n_2t_2 \cdots + n_nt_n}}$$

(4-point contact ball bearing)

$$Fa_{av} = \sqrt[3]{\frac{n_1t_1(|Fa_1|)^{3} + n_2t_2(|Fa_2|)^{3} \cdots + n_nt_n(|Fa_n|)^{3}}{n_1t_1 + n_2t_2 \cdots + n_nt_n}}$$

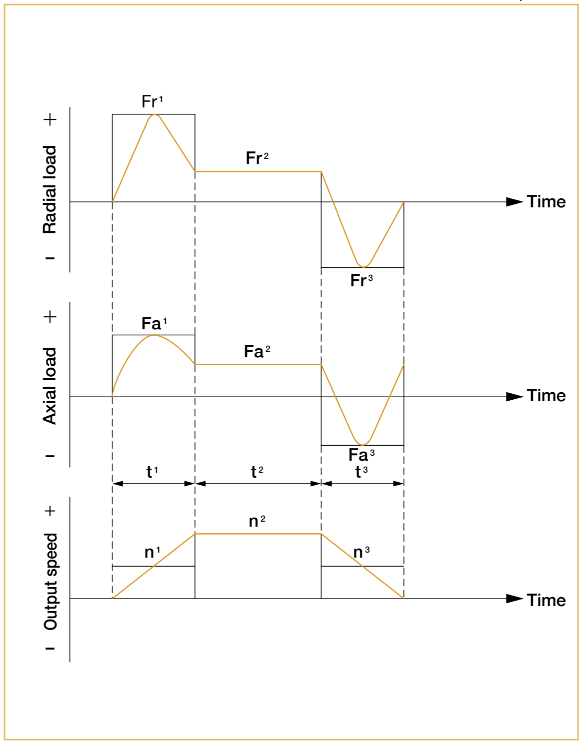
Note that the maximum axial load in t_1 is Fa_1 and the maximum axial load in t_3 is Fa_3.

How to calculate the average output speed (N_{av})

Formula 031-3

$$N_{av} = \frac{n_1t_1 + n_2t_2 \ldots + n_nt_n}{t_1 + t_2 \ldots + t_n}$$

Graph 031-1



How to calculate the radial load coefficient (X) and axial load coefficient (Y)

Formula 031-4

How to calculate the load coefficient		X	Y
$\frac{Fa_{av}}{Fr_{av}+2(Fr_{av}(Lr+R) + Fr_{av} \cdot La)/dp}$	<=1.5	1	0.45
$\frac{Fa_{av}}{Fr_{av}+2(Fr_{av}(Lr+R) + Fr_{av} \cdot La)/dp}$	>1.5	0.67	0.67

Symbols for Formula 031-4

Table 031-1

Fr_{av}	Average radial load	N(kgf)	See "How to calculate the average load." See Formula 031-1.
Fa_{av}	Average axial load	N(kgf)	See "How to calculate the average load." See Formula 031-2.
Lr, La	————	m	See fig. 030-1
R	Offset amount	m	See Fig. 030-1 and "Main roller bearing specifications" of each series
dp	Pitch circle diameter of a roller	m	See Fig. 030-1 and "Specification of the output bearing" of each series.

Life of the output bearing

Calculate life of the output bearing by Formula 032-1.
You can calculate the dynamic equivalent radial load (Pc) by Formula 032-2.

Formula 032-1

(Cross roller bearing)

$$L_{10} = \frac{10^6}{60 \times N_{av}} \times \left(\frac{C}{fw \cdot Pc}\right)^{10/3}$$

(4-point contact ball bearing)

$$L_{10} = \frac{10^6}{60 \times N_{av}} \times \left(\frac{C}{fw \cdot Pc}\right)^{3}$$

Formula 032-2

$$Pc = X \cdot \left(Fr_{av} + \frac{2(Fr_{av}(Lr+R) + Fr_{av} \cdot La)}{dp}\right) + Y \cdot Fa_{av}$$

Symbols for Formula 032-1

Table 032-1

L_{10}	Life	hour	———
N_{av}	Average output rated load speed	rpm	See "How to calculate the average load."
C	Basic dynamic rated load	N (kgf)	See "Specification of the output bearing" of each series.
Pc	Dynamic equivalent	N (kgf)	See Formula 032-2.
fw	Load coefficient	——	See Table 032-3.

Symbols for Formula 032-2

Table 032-2

Fr_{av}	Average radial load	N (kgf)	See "How to calculate the average load." See Formula 031-1.
Fa_{av}	Average axial load	N (kgf)	See "How to calculate the average load." See Formula 031-2.
dp	Pitch circle diameter	m	See Fig. 030-1 and "Specification of the output bearing" of each series.
X	Radial load coefficient	——	See Formula 031-4.
Y	Axial load coefficient	——	See Formula 031-4.
Lr, La	———	m	See Figure 030-1.
R	Offset	m	See Fig. 030-1 and "Specification of the output bearing" of each series.

Load coefficient

Table 032-3

Load status	fw
Steady operation without impact and vibration	1 to 1.2
Normal operation	1.2 to 1.5
Operation with impact and vibration	1.5 to 3

How to calculate life during oscillating motion

Calculate the life of the cross roller bearing during oscillating motion by Formula 033-1.

Formula 033-1

(Cross roller bearing)

$$Loc = \frac{10^6}{60 \times n1} \times \frac{90}{\theta} \times \left(\frac{C}{fw \cdot Pc}\right)^{10/3}$$

(4-point contact ball bearing)

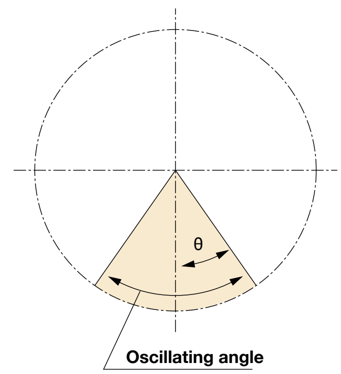
$$Loc = \frac{10^6}{60 \times n1} \times \frac{90}{\theta} \times \left(\frac{C}{fw \cdot Pc}\right)^{3}$$

Symbols for Formula 033-1

Table 033-1

Loc	Rated life for oscillating motion	hour	―――
n1	Round trip oscillation each minute	cpm	―――
C	Basic dynamic rated load	N（kgf）	―――
Pc	Dynamic equivalent radial load	N（kgf）	See Formula 032-2.
fw	Load coefficient	――	See Table 032-3.
θ	Oscillating angle /2	Degree	See Fig. 033-1.

Fig. 033-1



(Note) A small angle of oscillation (less than 5 degrees) may cause fretting corrosion to occur since lubrication may not circulate properly. Contact us if this happens.

Engineering Data
Component Sets
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How to calculate the static safety coefficient

Basic static rated load is an allowable limit for static load, but its limit is determined by usage. In this case, static safety coefficient of the cross roller bearing can be calculated by Formula 034-2.

Formula 034-1

$$fs = \frac{Co}{Po}$$

Formula 034-2

$$Po = Fr\,max + \frac{2M\,max}{dp} + 0.44Fa\,max$$

Symbols for Formula 034-1

Table 034-1

Co	**Basic static rated load**	N(kgf)	**See "Specification of the output bearing" of each series.**
Po	**Static equivalent radial load**	N(kgf)	**See Formula 034-2.**

Static Safety Coefficient

Table 034-3

Operating condition of the roller bearing	fs
When high rotation precision is required	≧3
When shock and vibration are expected	≧2
Under normal operating condition	≧1.5

Symbols for Formula 034-2

Table 034-2

$Fr\,max$	**Max. radial load**	N(kgf)	**See "How to calculate the maximum moment load" on Page 030.**
$Fa\,max$	**Max. axial load**	N(kgf)	
$M\,max$	**Max. moment load**	Nm(kgfm)	
dp	**Pitch circle diameter of a roller**	m	**See Fig. 030-1 and "Specification of the output bearing" of each series.**

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