Speed Reducers for Precision Motion Control

HarmonicDrive®

Reducer Catalog

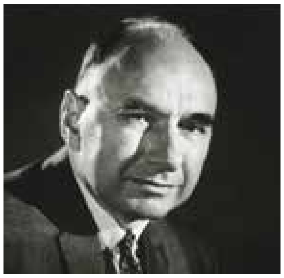
- Component Sets FR
- Engineering Data

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

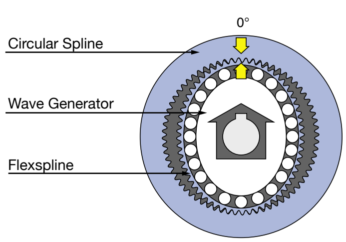
Operating Principle of HarmonicDrive® Gears

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.

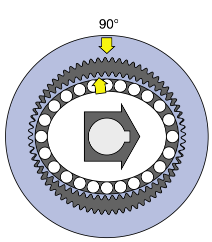
Wave Generator
The Wave Generator is a thin, raced-ball bearing fitted onto an elliptical hub. This serves as a high-efficiency torque converter and is generally mounted onto the input or motor shaft.

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.

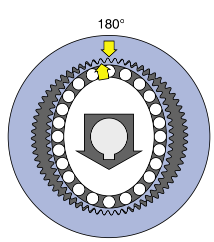
Circular Spline
The Circular Spline is a rigid ring with internal teeth. It engages the teeth of the Flexspline across the major axis of the Wave Generator ellipse. The Circular Spline has two more teeth than the Flexspline and is generally mounted onto a housing.



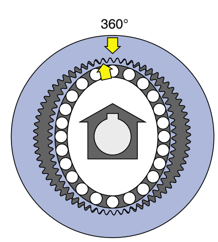
The Flexspline is slightly smaller in diameter than the Circular Spline and usually has two fewer teeth than the Circular Spline. The elliptical shape of the Wave Generator causes the teeth of the Flexspline to engage the Circular Spline at two opposite regions across the major axis of the ellipse.



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

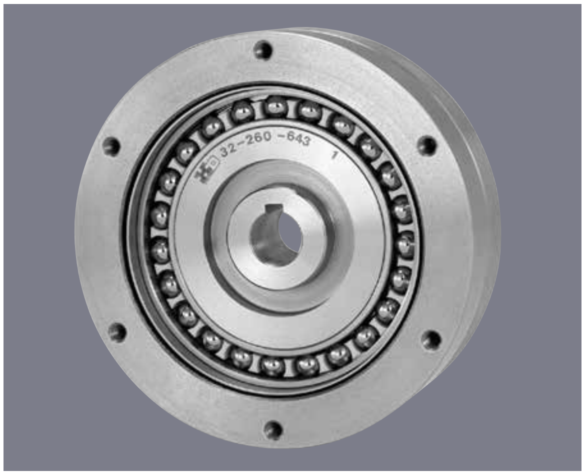
Harmonic Drive® gears have been evolving since the strain wave gear was first patented in 1955. Our innovative development and engineering teams have led us to significant advances in our gear technology. In 1988, Harmonic Drive successfully designed and manufactured a new tooth profile, the "S" tooth. 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®

FR Series

Component Set FR

Features



FR series component type

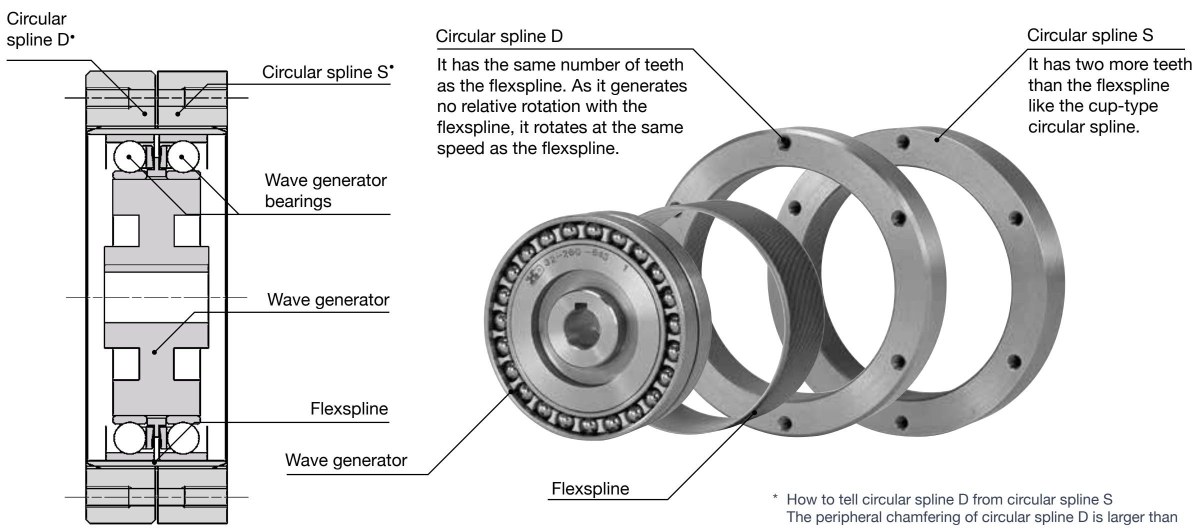
FR is a heavy duty pancacke gear that uses a double wave generator bearing. It consists of four parts like the FB series and operates using the same principle as the cup type.
It is basically structured in the same way as the FB series and supports high torque capacity by arranging the wave generator bearings in two lines and widening the tooth width of the circular spline and the flexspline.

Features

- ■ Flat and thin shape
- ■ High torque capacity
- ■ Compact and simple design
- ■ High positional and rotational accuracies
- ■ Coaxial input and output

Structure of the FR series component type

Fig. 112-1



* How to tell circular spline D from circular spline S
The peripheral chamfering of circular spline D is larger than that of circular spline S.

Ordering Code

FR - 20 - 80 - 2 - GR

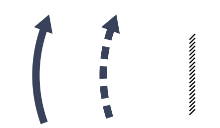
Table 113-1

Series	Size	Ratio*																			Model	
FR	14	50	—	88	—	100	110	—	—	—	—	—	—	—	—	—	—	—	—	—	2= Component type	R = Size 14 GR = Size 20-50
	20	50	—	80	—	100	—	—	128	—	—	—	160	—	—	—	—	—	—	—		
	25	50	—	80	—	100	—	120	—	—	—	—	160	—	200	—	—	—	—	—		
	32	50	78	—	—	100	—	—	—	131	157	—	—	—	200	—	—	—	260	—		
	40	50	—	80	—	100	—	—	128	—	—	—	160	—	200	—	—	258	—	—		
	50	—	—	80	—	100	—	120	—	—	—	—	160	—	200	—	242	—	—	—		
	65	—	78	—	—	—	104	—	—	—	132	158	—	—	—	208	—	—	260	—		
	80	—	—	80	96	—	—	—	128	—	—	—	160	194	—	—	—	258	—	320		
	100	—	—	80	—	100	—	120	—	—	—	—	160	—	200	—	242	—	—	320		

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

Rotational direction and reduction ratio

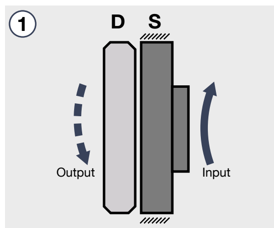
Fig. 113-1



Input Output Fixed

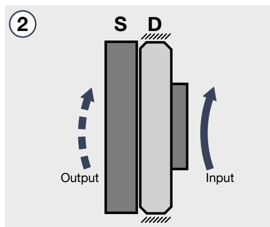
(Note) Contact us if you use the product as Accelerator (5) and (6).

I = Input
R = Reductin Ratio



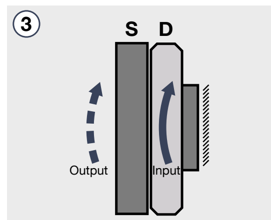
(1) Reducer
Input: Wave Generator
Output: Circular Spline D
Fixed: Circular Spline S

$i=\frac{-1}{R}$



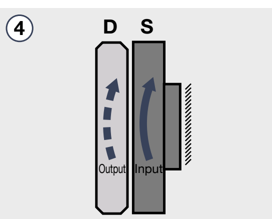
(2) Reducer
Input: Wave Generator
Output: Circular Spline S
Fixed: Circular Spline D

$i=\frac{1}{R+1}$



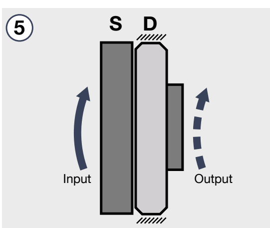
(3) Reducer
Input: Circular Spline D
Output: Circular Spline S
Fixed: Wave Generator

$i=\frac{R}{R+1}$



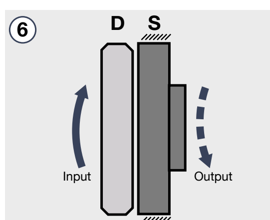
(4) Overdrive
Input: Circular Spline S
Output: Circular Spline D
Fixed: Wave Generator

$i=\frac{R+1}{R}$



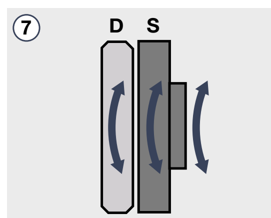
(5) Overdrive
Input: Circular Spline S
Output: Wave Generator
Fixed: Circular Spline D

$i=R+1$



(6) Overdrive
Input: Circular Spline D
Output: Wave Generator
Fixed: Circular Spline S

$i=-R$



(7) Differential
When all of the Wave Generator, the Circular Spline S and the Circular Spline D rotate, Combinations (1) through (6) are available.

Technical Data

Rating table

Table 114-1

Size	Ratio	Rated torque at 2000rpm		Repeated Peak Torque		Max. Average Load Torque		Max. Momentary Torque		Rated input rotational speed	Max. Input Speed, rpm		Limit for Average Input Speed, rpm		Moment of Inertia	
		Nm	kgfm	Nm	kgfm	Nm	kgfm	Nm	kgfm	rpm	Oil lubricant	Grease lubricant	Oil lubricant	Grease lubricant	I $\times10^{-4}$kgm^2	J $\times10^{-5}$kgfms^2
14	50	4.4	0.45	5.4	0.55	5.4	0.55	13.7	1.4	2000	6000	3600	4000	2500	0.060	0.061
	88	5.9	0.6	9.8	1.0	9.8	1.0	19.6*	2.0*							
	100	7.8	0.8	13.7	1.4	9.8	1.0	19.6*	2.0*							
	110	7.8	0.8	13.7	1.4	9.8	1.0	19.6*	2.0*							
20	50	25	2.5	34	3.5	34	3.5	69	7.0	2000	6000	3600	3600	2500	0.32	0.33
	80	34	3.5	41	4.2	41	4.2	72	7.3							
	100	40	4.1	53	5.4	49	5.0	94	9.6							
	128	40	4.1	67	6.8	49	5.0	102*	10.4*							
	160	40	4.1	77	7.9	49	5.0	86*	8.8*							
25	50	39	4.0	55	5.6	55	5.6	108	11.0	2000	5000	3600	3000	2500	0.7	0.71
	80	56	5.7	69	7.0	69	7.0	122	12.4							
	100	67	6.8	91	9.3	91	9.3	160	16.3							
	120	67	6.8	108	11.0	108	11.0	190	19.4							
	160	67	6.8	135	13.8	108	11.0	172*	17.6*							
	200	67	6.8	147	15.0	108	11.0	172*	17.6*							
32	50	76	7.8	108	11	108	11	216	22	2000	4500	3600	2500	2300	2.6	2.61
	78	108	11	137	14	137	14	245	25							
	100	137	14	176	18	176	18	323	33							
	131	137	14	255	26	216	22	451	46							
	157	137	14	294	30	216	22	500*	51*							
	200	137	14	314	32	216	22	372*	38*							
	260	137	14	314	32	216	22	372*	38*							
40	50	137	14	196	20	196	20	353	36	2000	4000	3300	2000	2000	6.8	6.9
	80	196	20	245	25	245	25	431	44							
	100	255	26	314	32	314	32	549	56							
	128	294	30	392	40	392	40	686	70							
	160	294	30	461	47	451	46	813	83							
	200	294	30	529	54	451	46	745	76*							
	258	294	30	627	64	451	46	745	76*							
50	80	363	37	441	45	441	45	784	80	1700	3500	3000	1700	1700	21	21
	100	470	48	578	59	578	59	1019	104							
	120	559	57	696	71	696	71	1225	125							
	160	559	57	833	85	833	85	1470	150							
	200	559	57	960	98	843	86	1411*	144*							
	242	559	57	1176	120	843	86	1411*	144*							
65	78	745	76	921	94	921	94	1617	165	1400	3000	2200	1400	1400	76	78
	104	1070	109	1340	137	1340	137	2360	241							
	132	1070	109	1650	168	1570	160	2890	295							
	158	1070	109	1970	201	1570	160	3450*	352*							
	208	1070	109	2180	222	1570	160	2590*	264*							
	260	1070	109	2200	224	1570	160	2590*	264*							
80	80	1320	135	1640	167	1640	167	2870	293	1200	2500	2000	1200	1200	213	217
	96	1660	169	2050	209	2050	209	3590	366							
	128	2300	235	2820	288	2830	289	4960	506							
	160	2350	240	3380	345	3130	319	5940	606							
	194	2350	240	4300	439	3130	319	6900*	704*							
	258	2350	240	4350	444	3130	319	5170*	528*							
	320	2350	240	4350	444	3130	319	5170*	528*							
100	80	2330	238	2870	293	2870	293	5040	514	1000	2000	1700	1000	1000	635	648
	100	3200	327	3940	402	3940	402	6920	706							
	120	3890	397	4780	488	4780	488	8400	857							
	160	4470	456	6230	636	5720	584	10950	1117							
	200	4470	456	7090	723	5720	584	12440	1269							
	242	4470	456	7960	812	5720	584	9410*	960*							
	320	4470	456	7960	812	5720	584	9410*	960*							

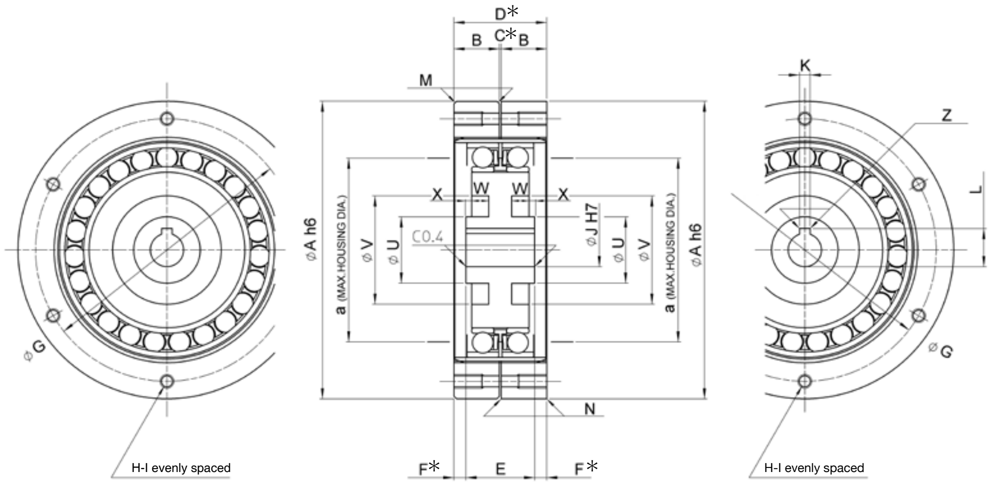
* Torque value limited by ratcheting.

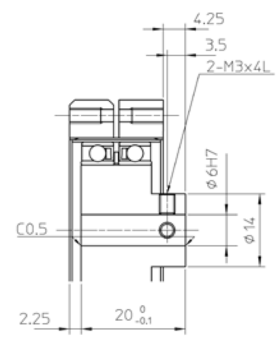
1. Moment of inertia: $I=\frac{1}{4}GD^2$
2. See Rating Table Definitions on Page 12 for details of the terms.

Load inertia = J

Outline dimensions

Fig. 115-1





FR-14

Dimensions

Table 115-1
Unit: mm

Symbol \ Size		14	20	25	32	40	50	65	80	100
ØA (h6)		50	70	85	110	135	170	215	265	330
B		8.5	12	14	18	21	26	35	41	50
C*		1	1	1	1	1	1	1	1	1
D*		18	25	29	37	43	53	71	83	101
E $^{0}_{-0.1}$		—	17.3	20	25.9	31.5	39.1	50.5	62	77.2
F*		—	3.85	4.5	5.55	5.75	6.95	10.25	10.5	11.9
ØG		44	60	75	100	120	150	195	240	290
H		6	6	6	6	6	6	6	8	8
I		M3×6	M3×6	M4×8	M5×10	M6×12	M8×16	M10×20	M10×20	M12×24
ØJ (H7)	Standard	6	9	11	14	14	19	24	28	28
	Max. size	8	11	11	17	20	26	26	32	33
K (J_{S9})		—	3	4	5	5	6	8	8	8
L $^{+0.1}_{0}$		—	10.4	12.8	16.3	16.3	21.8	27.3	31.3	31.3
M		c1	c1	c1.5	c1.5	c1.5	c1.5	c1.5	c2	c2
N		c0.2	c0.2	c0.2	c0.2	c0.4	c0.4	c0.4	c0.4	c0.4
a		29	42	53	69	84	105	138	169	211
ØU		—	—	22	28	32	38	44	52	58
ØV		—	—	32	42	52	62	86	100	128
W		—	—	4.8	6.1	7.6	9.8	12.6	16	19.7
X		—	—	1.6	1.9	2.5	3.2	4.4	5.1	6.3
Z		—	R0.08 to 0.16	R0.08 to 0.16	R0.08 to 0.25	R0.08 to 0.25	R0.08 to 0.25	R0.08 to 0.25	R0.08 to 0.25	R0.08 to 0.25
Mass	kgf	0.2	0.5	0.8	1.7	3.0	6.0	12.0	22.3	42.6

(Note) For Circular spline D, the peripheral chamfering is M.

*The C, D and F values indicate relative position of individual gearing components (wave generator, flexspline, circular spline). Please strictly adhere to these values when designing your housing and mating parts.

● Four parts (wave generator, flexspline, circular spline D, circular spline S) are not assembled when delivered.

Component Set FR

Efficiency

The efficiency varies depending on the following conditions.

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

Measurement condition Table 116-1

Installation	Based on recommended tolerance.		
Load torque	The rated torque shown in the rating table (see page 114)		
Lubricant	Grease	Name	Harmonic Grease SK-1A
			Harmonic Grease SK-2
	Oil		Industrial gear oil class-2
	Quantity		Recommended quantity (see page 122)

* Contact us for oil lubrication.

■ Efficiency compensation coefficient

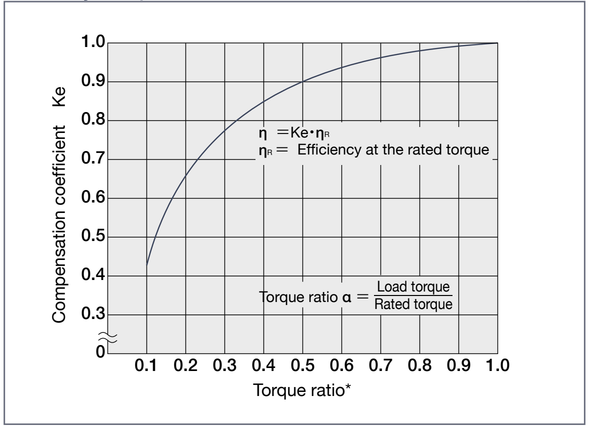
If the load torque is lower than the rated torque, the efficiency will be lower. Calculate the compensation coefficient Ke from Graph 116-1 to calculate the efficiency using the following example.

Calculation Example

Efficiency η (%) under the following condition is calculated from the example of FR-20-80-2GR.
Input rotational speed: 1000 rpm
Load torque: 19.6 Nm
Lubrication: 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 114), the torque ratio α is 0.58.
(α=19.6/34=0.58)

- The efficiency compensation coefficient is Ke=0.86 from Graph 116-1.
- Efficiency η at load torque 19.6 Nm: η=Ke•ηR=0.86 x 65=56%

Efficiency compensation coefficient Graph 116-1

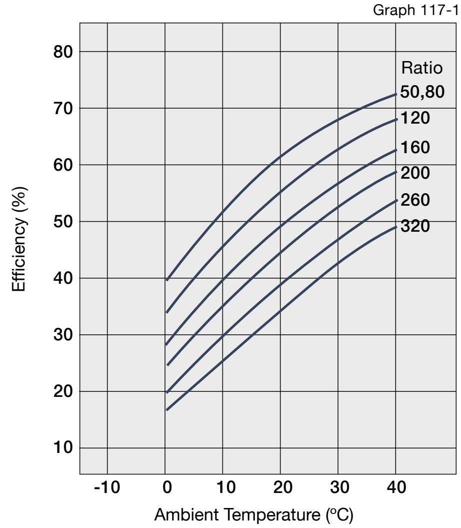


* Efficiency compensation coefficient Ke=1 holds when the load torque is greater than the rated torque.

■ Efficiency at rated torque (oil lubrication)

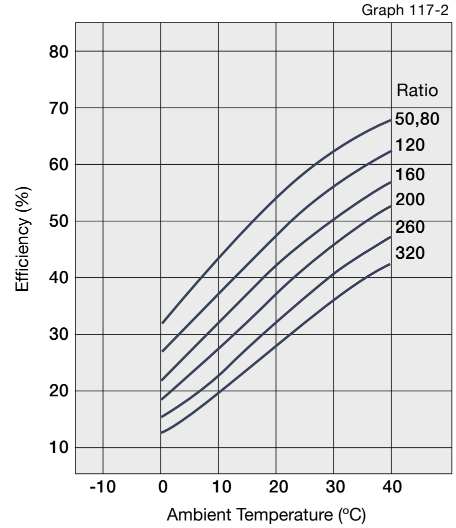
Input speed: 500rpm

Graph 117-1



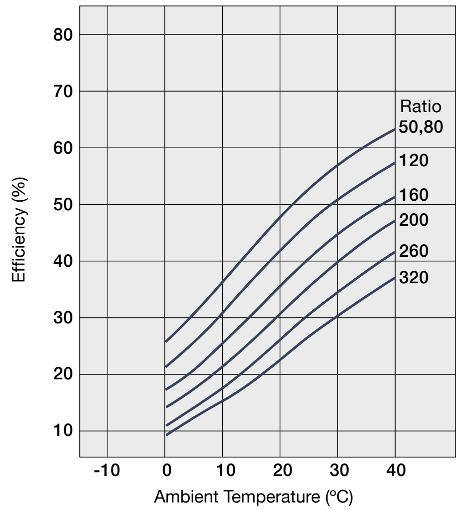
Input speed: 1000rpm

Graph 117-2



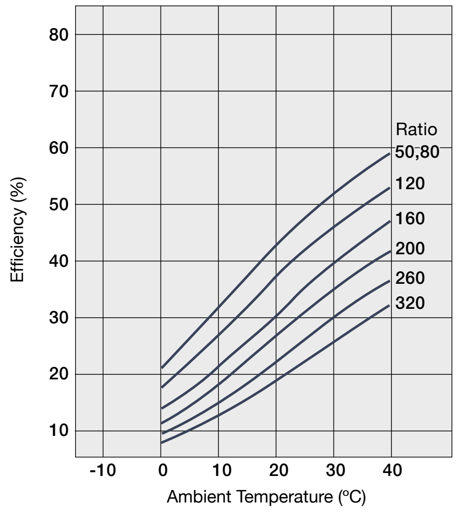
Input speed: 2000rpm

Graph 117-3



Input speed: 3500rpm

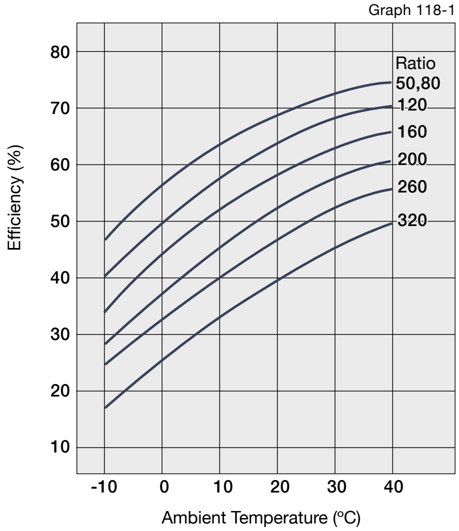
Graph 117-4



■ Efficiency at rated torque (grease lubrication)

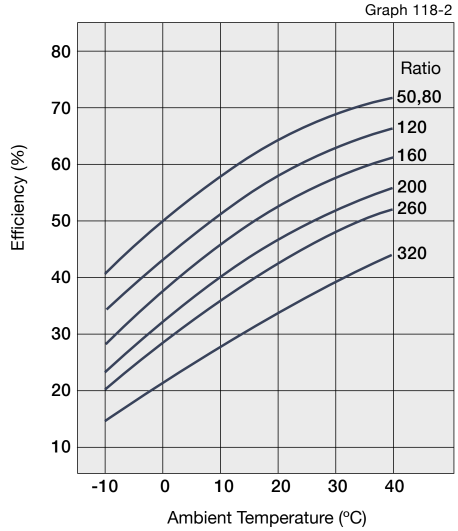
Input speed: 500rpm

Graph 118-1



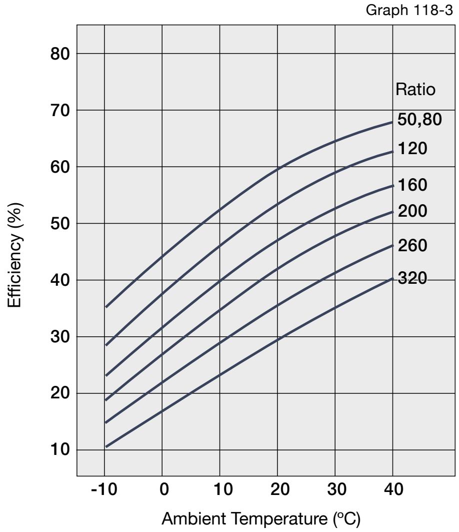
Input speed: 1000rpm

Graph 118-2



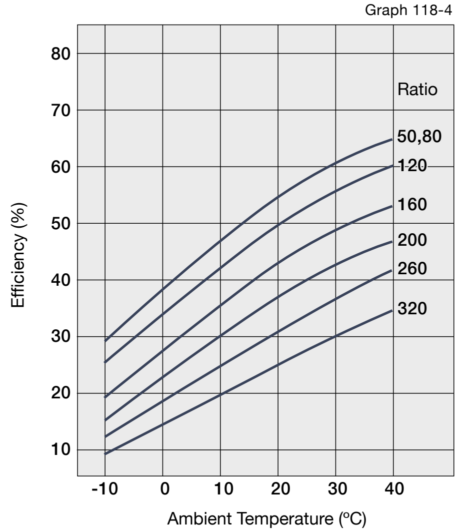
Input speed: 2000rpm

Graph 118-3



Input speed: 3500rpm

Graph 118-4



No-load running torque, starting torque, backdriving torque

Values indicated are from actual tests with the component sets assembled in their housings, and inclusive of friction resistance of oils seals, and churning of oil.

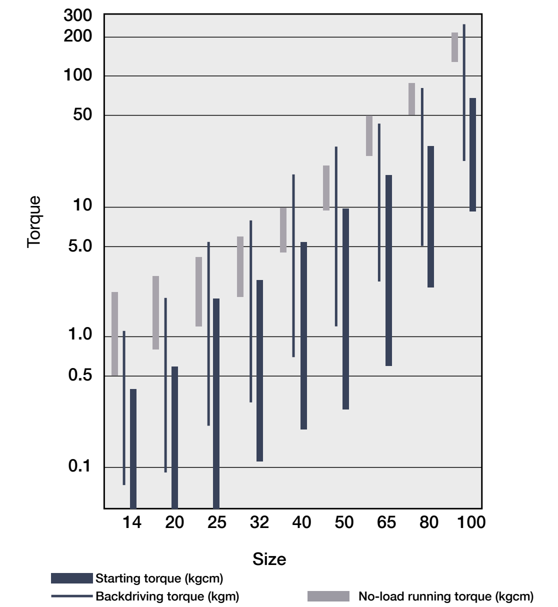
(1) No-load running torque····· No-load running torque is the torque which is required to rotate the input side (high speed side), when there is no load on the output side (low speed side). The value in the graph indicates the condition when the input rotational speed is 1500 rpm and the oil temperature is about 40ºC.

(2) Starting torque···················This is the static torque required to start the high-speed shaft in a no-load condition.

(3) Backdriving torque ··········· This is the static torque required to start the low-speed shaft in a no-load condition.

Running torque, starting torque, backdriving torque

Fig. 119-1



Lost motion and the spring constant

Lost motion and the spring constant of the pancake gear is the value when the wave generator or one circular spline is fixed and when a torque is applied to the dynamic spline.

Table 120-1

Size	Lost motion (arc min)		Spring constant (kgm/min)	
	± Load (kgm)	Standard product	Load (kgm)	Spring constant
14	0.04	max. 3.0	1.26	0.3
20	0.12	3.0	3.69	0.9
25	0.23	3.0	7.20	2.1
32	0.46	3.0	15.78	4.4
40	0.92	3.0	29.50	7.8
50	1.73	3.0	57.60	16
65	3.9	3.0	126.7	27
80	7.4	3.0	236.2	52
100	14.4	3.0	460.8	100

■ Description on lost motion and spring constant

When assembled, rotation of the Wave Generator as a high speed input member imparts a rotating elliptical shape to the Flexspline. This causes progressive engagement of its external teeth with the internal teeth of the Circular Spline. The fixed Circular Spline, having a larger number of teeth than the Flexspline causes the latter to precess at a rate determined by the ratio of tooth difference to the total number of teeth. With the same number of teeth as the Flexspline, The Dynamic Spline rotates with, and at the same speed as, the Flexspline and is the output member of the drive.

(1) Lost motion (L/M)

The lost motion is the total value of rotational angle of low-speed shaft when the high-speed shaft is fixed in rotational direction with the drive installed and when slight load torque (see Table 120-1) is applied to the low-speed shaft the other way round.

(2) Spring constant

By increasing the load torque gradually in the same manner as the lost motion and applying the load the other way round, "load torque - torsional angle" diagram emerges as shown in Fig. 120-2. The average spring constant obtained by this diagram is shown in Table 120-1. (This value is only for the HarmonicDrive® components.)

■ Example of calculation

Use model number FR-40-160-2A-GR to fix the input shaft in rotational direction, and apply the load (30kgfm) rated in the catalog to the output shaft, and then obtain the torsional angle.

Torsional angle $\theta = \frac{L \cdot M}{2} + \frac{1}{K}(T - T_{L \cdot M})$

$= 1.5 + \frac{1}{7.8}(30 - 0.92)$

$= 5.23$ arc min

Maximum value "θmax" when rotated the other way round is

$\theta max = 2 \cdot \theta = 10.46$ arc min

Fig. 120-1

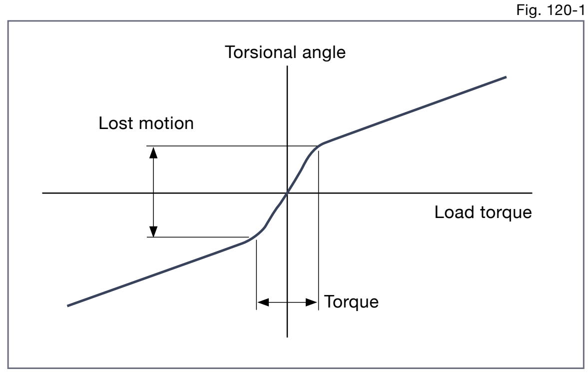


Fig. 120-2

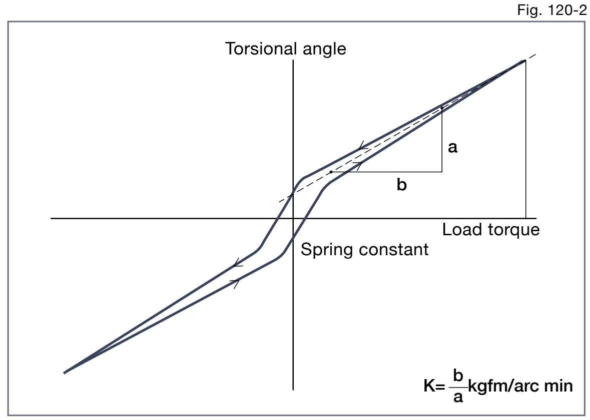
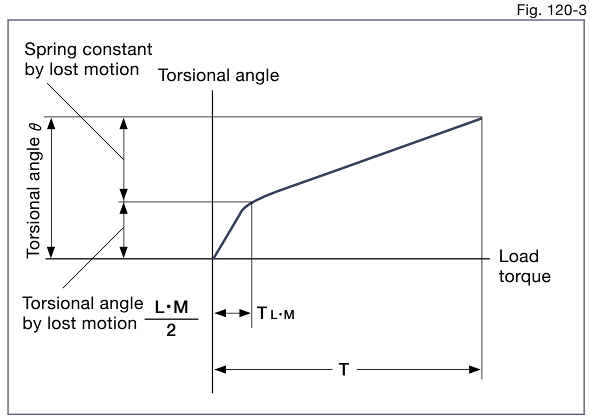


Fig. 120-3



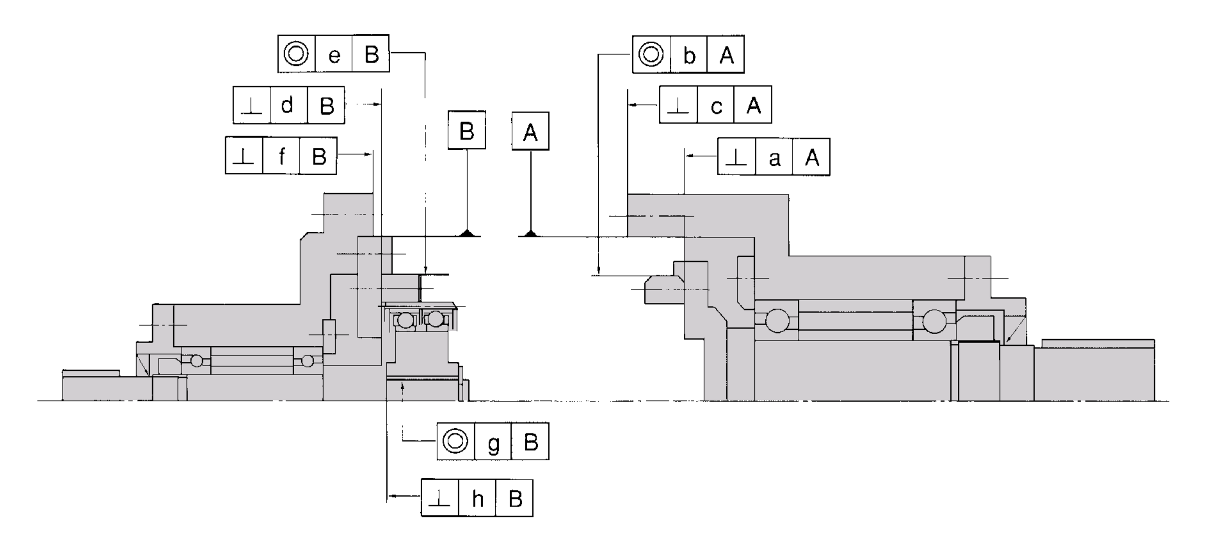
Design Guide

Recommended tolerances for assembly

Maintain the recommended assembly tolerances shown in Figure 121-1 and Table 121-1 for maximum performance of your FR gear.

Recommended tolerances for assembly

Fig. 121-1



Recommended tolerances for assembly

Table 121-1

Unit: mm

Symbol \ Size	14	20	25	32	40	50	65	80	100
a	0.013	0.017	0.024	0.026	0.026	0.028	0.034	0.043	0.057
b	0.015	0.016	0.016	0.017	0.019	0.024	0.027	0.033	0.038
c	0.016	0.020	0.029	0.031	0.031	0.034	0.041	0.052	0.068
d	0.013	0.017	0.024	0.026	0.026	0.028	0.034	0.043	0.057
e	0.015	0.016	0.016	0.017	0.019	0.024	0.027	0.033	0.038
f	0.016	0.020	0.029	0.031	0.031	0.034	0.041	0.052	0.068
g	0.011	0.013	0.016	0.016	0.017	0.021	0.025	0.030	0.035
h	0.007	0.010	0.012	0.012	0.012	0.015	0.015	0.015	0.015

Installation of the circular spline

Conduct design and part control corresponding to the load condition for installation of the circular spline. Transmission torques by the recommended bolts and tightening torques are shown in the following table.

Installation with bolts

Table 121-1

Item \ Size		14	20	25	32	40	50	65	80	100
Number of bolts		6	6	6	6	6	6	6	8	8
Bolt size		M3	M3	M4	M5	M6	M8	M10	M10	M12
Pitch Circle Diameter	mm	44	60	75	100	120	150	195	240	290
Clamp torque	Nm	2.0	2.0	4.5	9.0	15.3	37	74	74	128
	kgfm	0.20	0.20	0.46	0.92	1.56	3.8	7.5	7.5	13.1
Torque transmission	Nm	54	74	159	338	573	1300	2680	4410	7750
	kgfm	5.5	7.5	16	34	58	132	273	450	790

(Table 121-1/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

Component Set FR

Precautions on assembly

Maintain the recommended tolerances shown in Figure 122-1 and Table 122-1 for optimal performance.

Lubrication

There are two types of lubrication; oil lubrication and grease lubrication. Although oil lubrication is common, grease lubrication is applicable to intermittent operation.

■ Oil lubrication

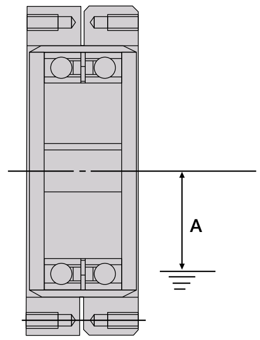
1. Types of Oil

The specified standard lubricant is “Industrial gear oil class-2 (extreme pressure) ISO VG68.” (Page 18).

2. Oil quantity

The recommended oil level is shown in Table 122-1.

Fig. 122-1



Oil level

Table 122-1
Unit: mm

Size	14	20	25	32	40	50	65	80	100
A	7	12	15	31	38	44	62	75	94

■ Grease lubrication

Different from oil lubrication, as a cooling effect is not expected from grease lubrication, it is only available for short operation.

- Operating condition: ED%·· 10% or less, continuous operation for 10 minutes or less, the maximum allowable input rotational speed in Table 114-1 or less
- Recommended grease:····· Harmonic Grease SK-1A for sizes 20 to 100
  Harmonic Grease SK-2 for size 14

(Note) If you use the product over ED% or the maximum allowable rotational speed, the grease will deteriorate, will not work as a lubricating mechanism and will result in damaging the reducer earlier. Extreme care should be taken.

Engineering Data

Engineering Data

Tooth Profile

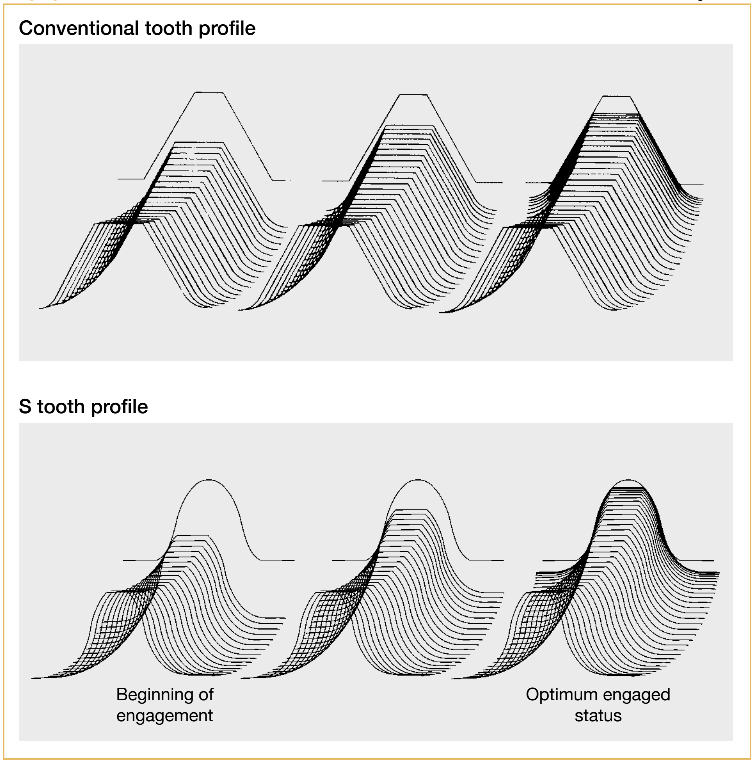
■ S tooth profile

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.

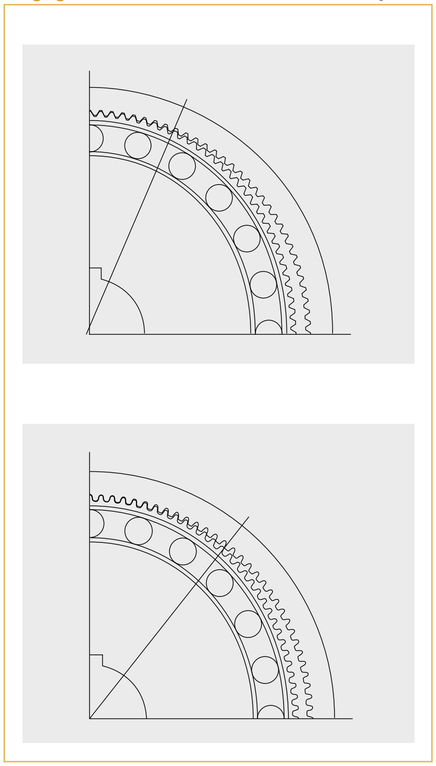
Additionally the large tooth root radius increases the tooth strength compared with an involute tooth. This technological innovation results in high torque, high torsional stiffness, long life and smooth rotation.

*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

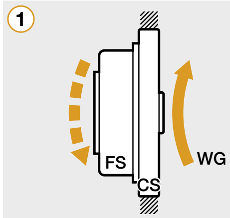
■ Rotational direction

Fig. 010-1

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

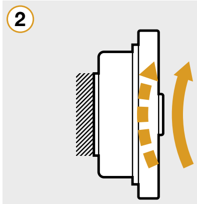
Input Output

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



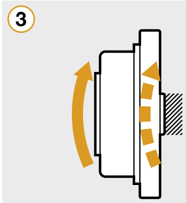
(1) Reducer
Input: Wave Generator (WG)
Output: Flexspline (FS)
Fixed: Circular Spline (CS)

$i=\frac{-1}{R}$



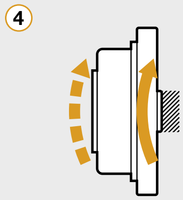
(2) Reducer
Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline

$i=\frac{1}{R+1}$



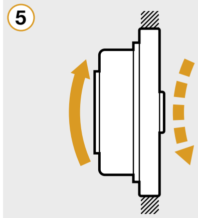
(3) Reducer
Input: Flexspline
Output: Circular Spline
Fixed: Wave Generator

$i=\frac{R}{R+1}$



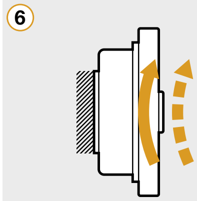
(4) Overdrive
Input: Circular Spline
Output: Flexspline
Fixed: Wave Generator

$i=\frac{R+1}{R}$



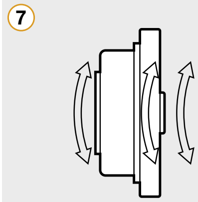
(5) Overdrive
Input: Flexspline
Output: Wave Generator
Fixed: Circular Spline

$i=-R$



(6) Overdrive
Input: Circular Spline
Output: Wave Generator
Fixed: Flexspline

$i=R+1$



(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

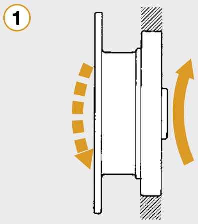
■ Rotational direction

Fig. 010-2

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

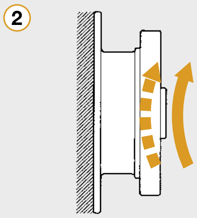
Input Output

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



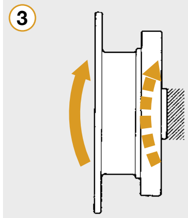
(1) Reducer
Input: Wave Generator
Output: Flexspline
Fixed: Circular Spline

$i=\frac{-1}{R}$



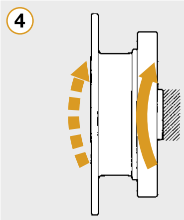
(2) Reducer
Input: Wave Generator
Output: Circular Spline
Fixed: Flexspline

$i=\frac{1}{R+1}$



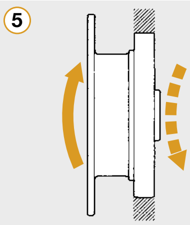
(3) Reducer
Input: Flexspline
Output: Circular Spline
Fixed: Wave Generator

$i=\frac{R}{R+1}$



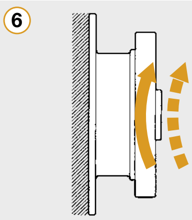
(4) Overdrive
Input: Circular Spline
Output: Flexspline
Fixed: Wave Generator

$i=\frac{R+1}{R}$



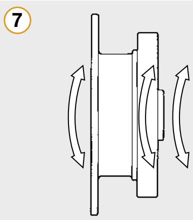
(5) Overdrive
Input: Flexspline
Output: Wave Generator
Fixed: Circular Spline

$i=-R$



(6) Overdrive
Input: Circular Spline
Output: Wave Generator
Fixed: Flexspline

$i=R+1$



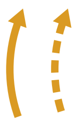
(7) Differential
When all of the wave generator, the flexspline and the circular spline rotate, Combinations (1) through (6) are available.

Pancake

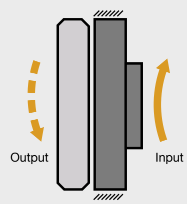
Series: FB and FR

■ Rotational direction

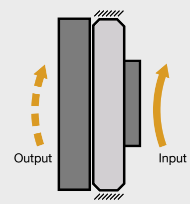
Fig. 11-1



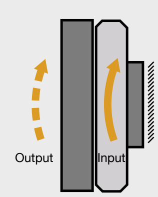
(Note) Contact us if you use the product as Accelerator (5) and (6).



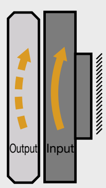
(1) Reducer
Input: Wave Generator
Output: Circular Spline D
Fixed: Circular Spline S
$i = \frac{-1}{R}$



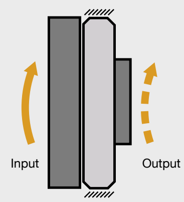
(2) Reducer
Input: Wave Generator
Output: Circular Spline S
Fixed: Circular Spline D
$i = \frac{1}{R+1}$



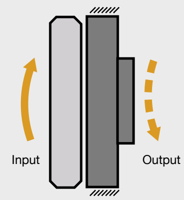
(3) Reducer
Input: Circular Spline D
Output: Circular Spline S
Fixed: Wave Generator
$i = \frac{R}{R+1}$



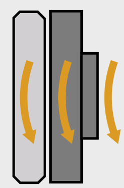
(4) Overdrive
Input: Circular Spline S
Output: Circular Spline D
Fixed: Wave Generator
$i = \frac{R+1}{R}$



(5) Overdrive
Input: Circular Spline S
Output: Wave Generator
Fixed: Circular Spline D
$i = R+1$



(6) Overdrive
Input: Circular Spline D
Output: Wave Generator
Fixed: Circular Spline S
$i = -R$



(7) Differential
When all of the Wave Generator, the Circular Spline S and the Circular Spline D rotate, Combinations (1) through (6) are available.

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

Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

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

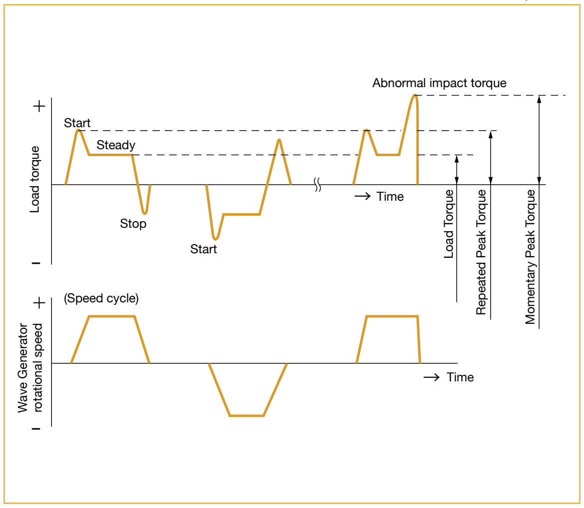
Do not exceed the allowable rating. (calculation formula of the average input speed: Page 14).

■ 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.

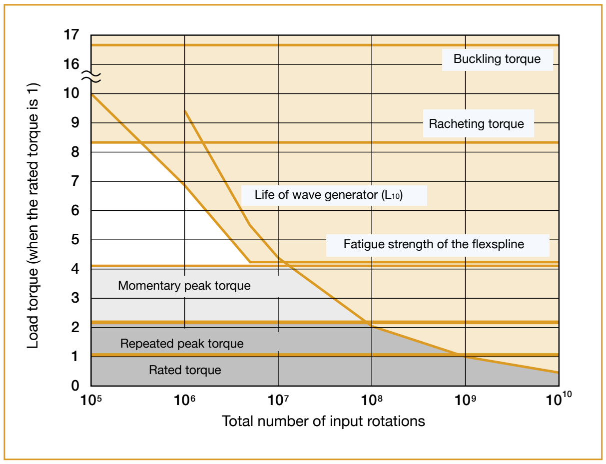
Table 012-1

	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.

Relative torque rating

Graph 012-2



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

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)

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

$$N = \frac{1.0 \times 10^4}{2 \times \frac{n}{60} \times t}$$

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

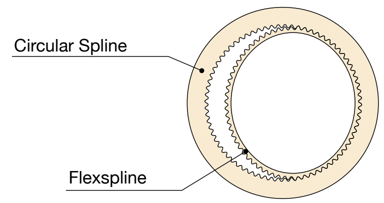
When excessive torque (8 to 9 times rated torque) is applied while the gear is in motion, the teeth between the Circular Spline and Flexspline may not engage properly.
This phenomenon is called ratcheting and the torque at which this occurs is called ratcheting torque. Ratcheting may cause the Flexspline 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.

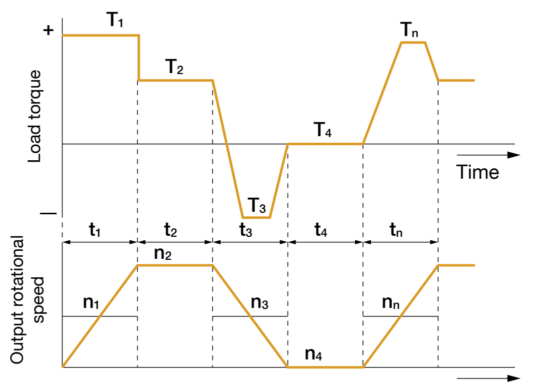
Product Sizing & Selection

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).

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

↓

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 (Ns) 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 ni ***max*** = 1800 rpm
(Restricted by motors)

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)

$$n_{i\,av} = 12\text{ rpm}\cdot 120 = 1440\text{ rpm}$$

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

$$n_{i\,max} = 14\text{ rpm}\cdot 120 = 1680\text{ rpm}$$

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

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

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.

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 0ºC to + 40ºC
	SK-2 0ºC to + 40ºC
	4B No.2 –10ºC to + 70ºC
Oil	ISO VG68 0ºC to + 40ºC

* 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 (25ºC)	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	197ºC	198ºC	247ºC
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 :△

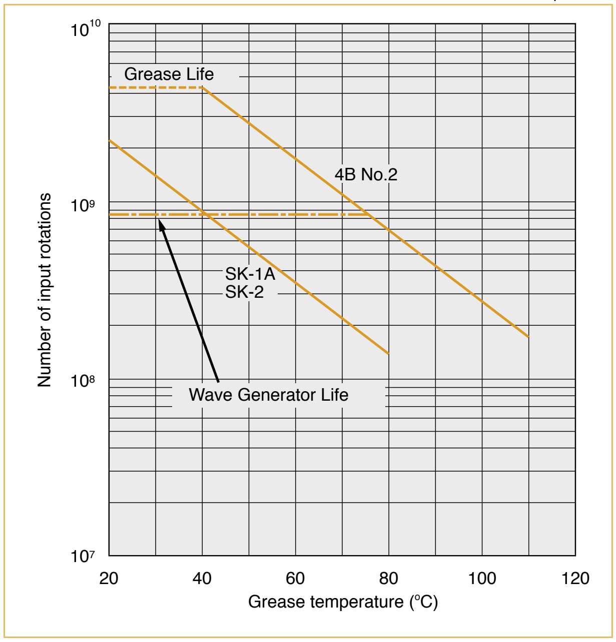
■ When to replace grease

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 80°C 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˚C to + 110˚C	−50˚C to + 130˚C

High temperature lubricant

Table 019-2

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

Low temperature lubricant

Table 019-3

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

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

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

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

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

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 .

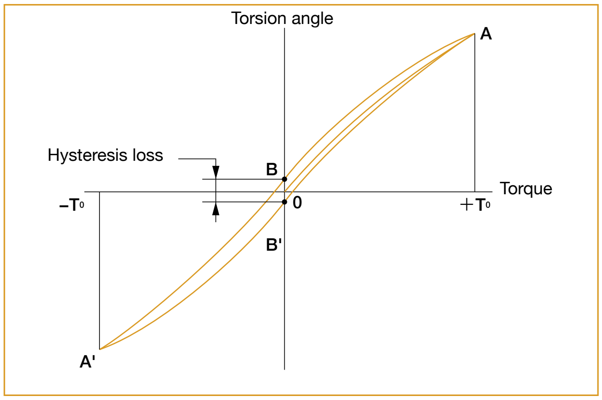
■ Hysteresis loss (Silk hat and cup style only)

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.

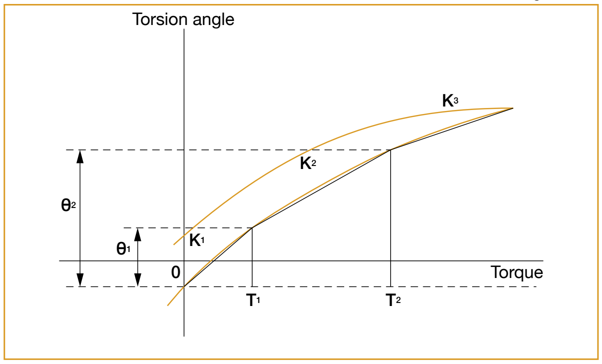
Torque - torsion angle diagram

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

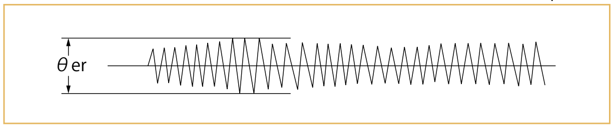


Table 021-1

$\theta\,er$	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	

Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

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

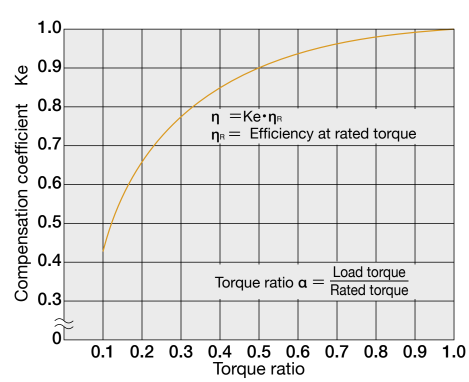
Efficiency η (%) under the following condition is obtained from the example of CSF-20-80-2A-GR.
Input rotational speed: 1000 rpm
Load torque: 19.6 Nm
Lubrication method: Grease lubrication (Harmonic Grease SK-1A)
Lubricant temperature: 20°C
Since the rated torque of size 20 with a reduction ratio of 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: $\eta = Ke \cdot \eta_R = 0.93 \times 78 = 73\%$

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.

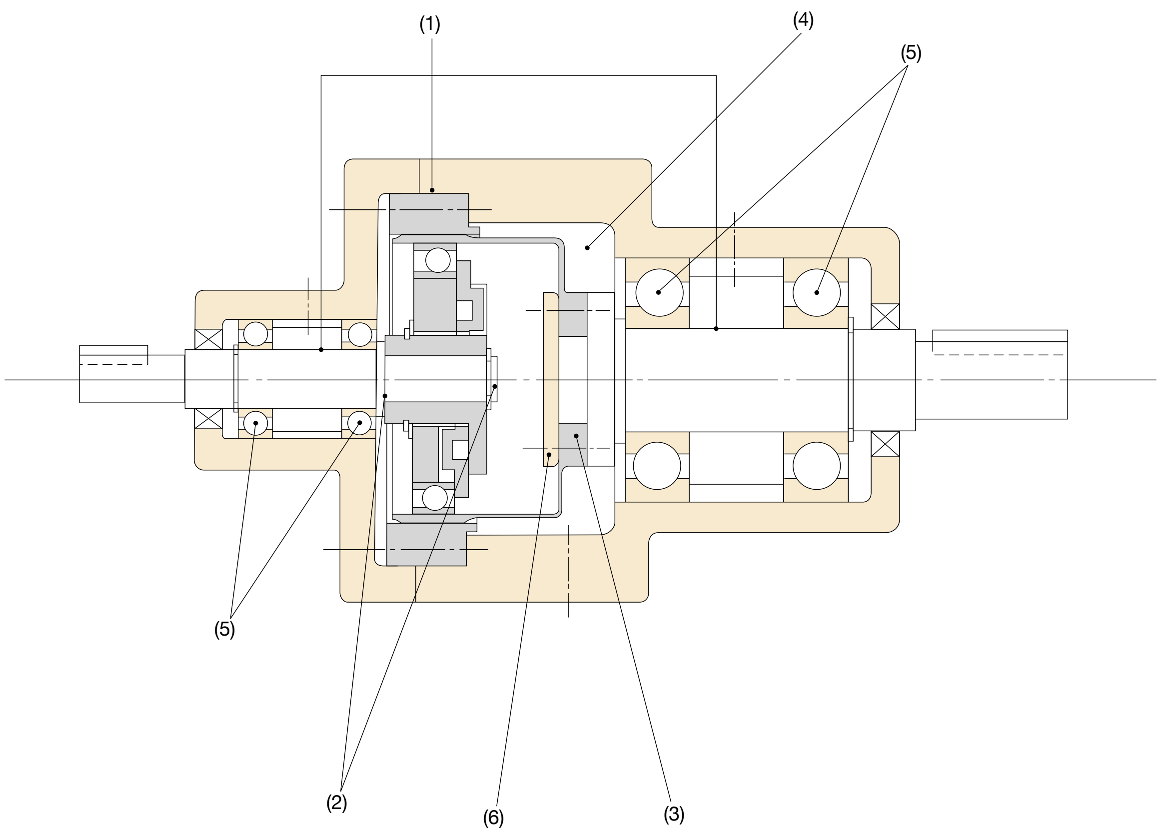
(3) Even though a HarmonicDrive® gear is compact, it transmits large torques. Therefore, assure that all required bolts are used to fasten the circular spline and flexspline and that they are tightened to the recommended torque.

(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.

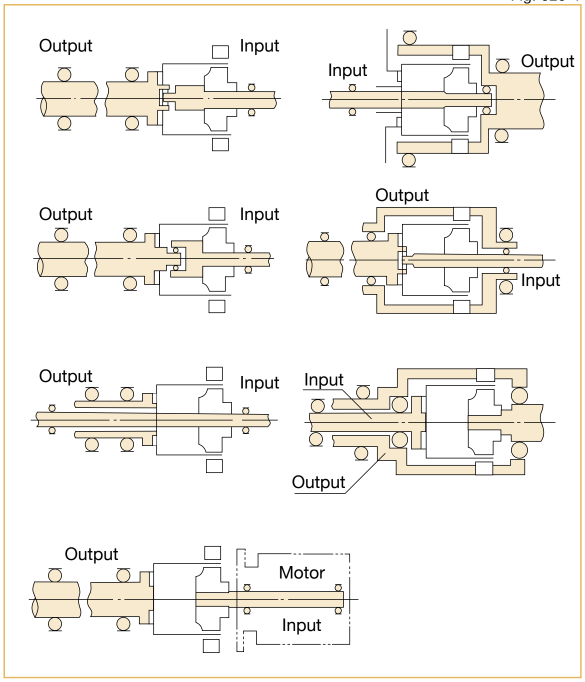
Fig. 024-1



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

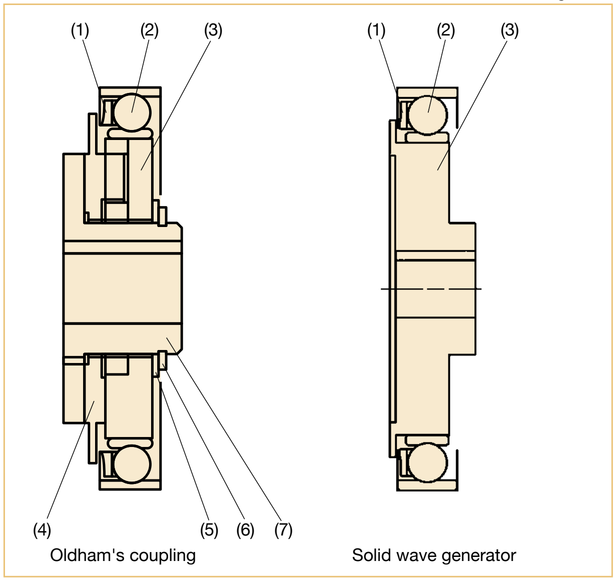


Wave generator

■ 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.

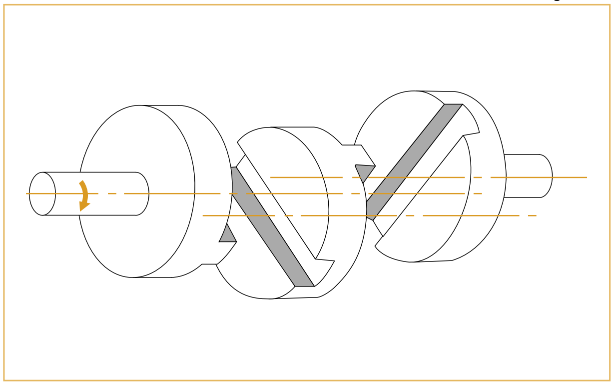
Fig. 026-1



(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

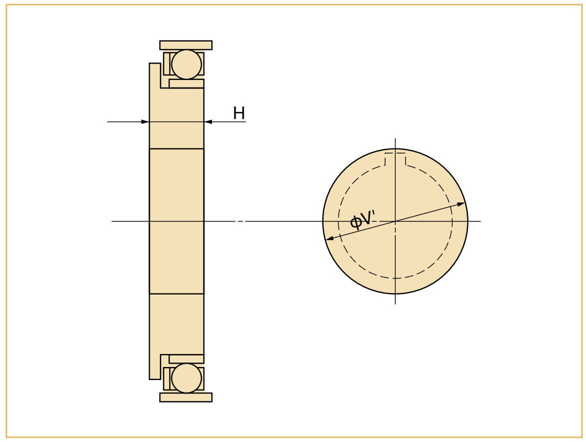
The standard hole dimension of the wave generator is shown for each size. The dimension can be changed within a range up to the maximum hole dimension. We recommend the dimension of keyway based on JIS standard. It is necessary that the dimension of keyways should sustain the transmission torque.

* 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

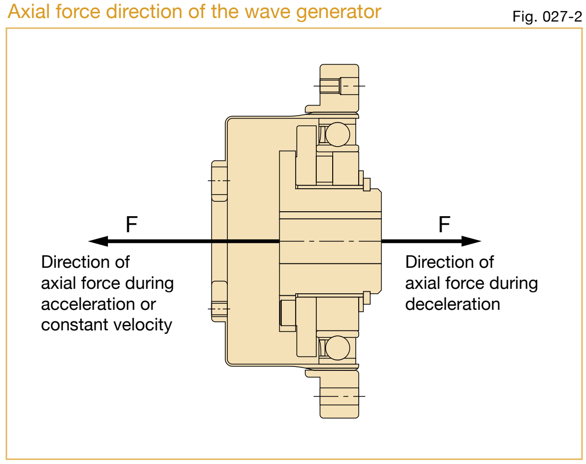
■ Axial Force of Wave Generator

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

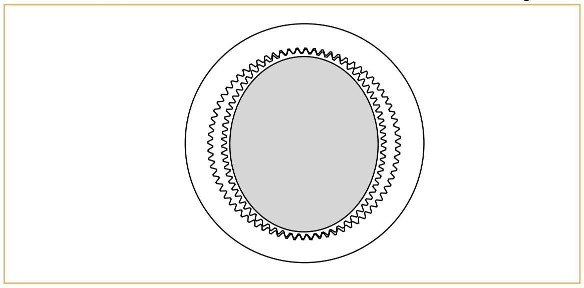
Although the Harmonic Drive® gears come with some corrosion protection, the gear can rust if exposed to the environment. The gear external surfaces typically have only a temporary corrosion inhibitor and some oil applied. If an anti-rust product is needed, please contact us to review the options.

"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.

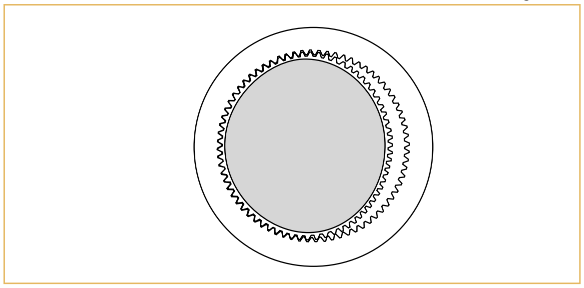
Normal engagement status

Fig. 029-1



"Dedoidal" status

Fig. 029-2



■ 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".

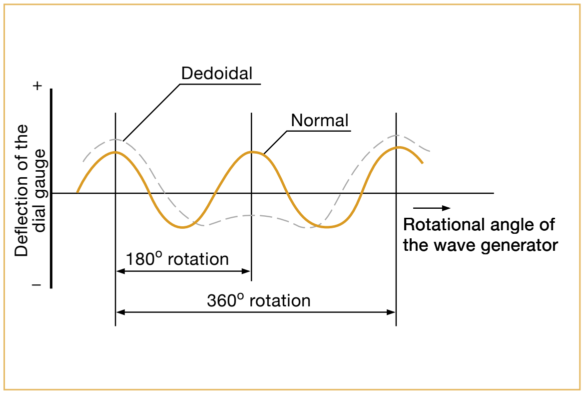
2) Turn the wave generator in a no-load condition if it is attached to a motor. If the average current value of the motor is about 2 to 3 times the normal value, it may be "dedoidal".

(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.

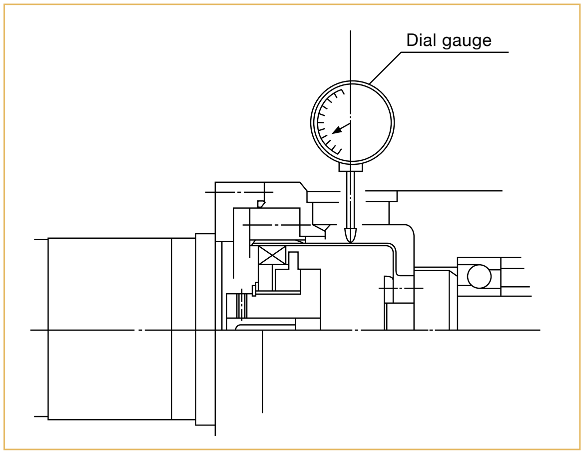
Deflection of the dial gauge

Graph 029-3



Measuring the deflection on the body of the flexspline

Fig. 029-4



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

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

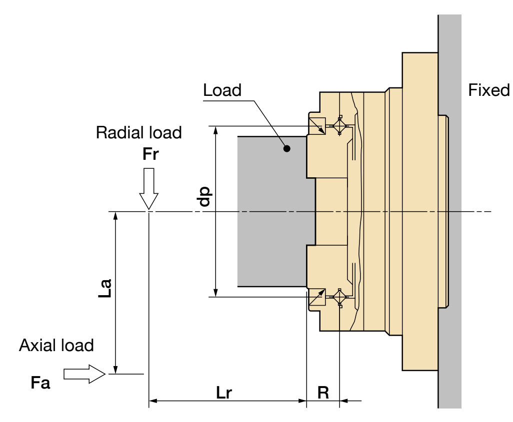
Symbols for Formula 030-1

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)

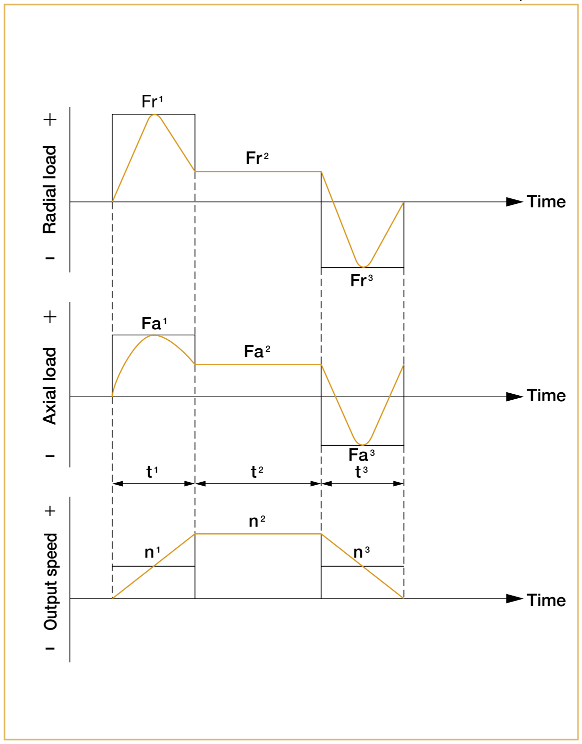
$$Fa_{av} = \sqrt[10/3]{\frac{n_1t_1(|Fa_1|)^{10/3} + n_2t_2(|Fa_2|)^{10/3} \cdots + n_nt_n(|Fa_n|)^{10/3}}{n_1t_1 + n_2t_2 \cdots + n_nt_n}}$$

(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.

Graph 031-1



How to calculate the average output speed (Nav)

Formula 031-3

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

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.

Engineering Data
Component Sets
Gear Units
Phase Adjusters
Gearheads & Actuators

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)

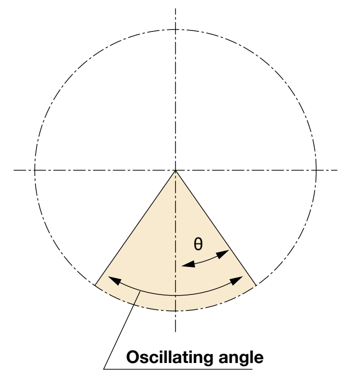
$$Loc = \frac{10^6}{60 \times n1} \times \frac{90}{\theta} \times \left(\frac{C}{fw \cdot Pc}\right)^{3}$$

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
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Gearheads & Actuators

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

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

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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