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.

![Diagram of HarmonicDrive Gears](image)

- **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.
### FB Series

#### Component Set FB

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Precautions on installation:

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. Bolts should not rotate freely when tightening and should not have any irregularity due to the bolt hole being misaligned or oblique.
6. 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 with the specified torque. Tighten them in an even, crisscross pattern.
7. Avoid pinning the circular spline if possible as it can reduce the rotational precision and smoothness of operation.
Features

**FB series component type**
FB is a cup type component set, without the bottom of the cup. This series is also referred to as "pancake style". It consists of four parts and operates using the same principle as the cup type of the CSG/CSF series. The flexspline is shaped like the flexspline of the cup type with a cut bottom and is structured to have an additional circular spline with the same number of teeth as the flexspline.

**Features**
- Flat and thin shape
- Compact and simple design
- High positional and rotational accuracies
- Coaxial input and output

**Structure of the FB series component type**

Circular spline D
It has the same number of teeth as the flexspline. As it does not generate relative rotation with the flexspline, it rotates at the same speed as the flexspline.

Circular spline S
It has two more teeth than the flexspline, like the cup-type circular spline.

- 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.
Component Set FB

Ordering Code

FB - 20-80 - 2 - GR

<table>
<thead>
<tr>
<th>Series</th>
<th>Size</th>
<th>Ratio*</th>
<th>Model</th>
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<tr>
<td>FB</td>
<td>14</td>
<td>50 - 88</td>
<td>110 -</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>50 - 80</td>
<td>100 -</td>
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<tr>
<td></td>
<td>25</td>
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<td>40</td>
<td>50</td>
<td>80 - 100</td>
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</tr>
<tr>
<td>50</td>
<td>-</td>
<td>80 - 100</td>
<td>-</td>
</tr>
</tbody>
</table>

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

Rotational direction and reduction ratio

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

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

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

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

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

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

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

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

### Rating table

<table>
<thead>
<tr>
<th>Size</th>
<th>Ratio</th>
<th>14</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>50</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Rated torque at 2000rpm (Nm kglm)</td>
<td>2.6</td>
<td>2.7</td>
<td>3.2</td>
<td>3.3</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Repeated peak torque (Nm)</td>
<td>3.2</td>
<td>3.3</td>
<td>3.2</td>
<td>3.3</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Max. Average load torque (Nm)</td>
<td>6.9</td>
<td>0.7</td>
<td>15.7</td>
<td>1.6</td>
<td>15.7</td>
<td>1.6</td>
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<tr>
<td></td>
<td>Max. Momentary torque (Nm)</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
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<tr>
<td></td>
<td>Rated input rotational speed (rpm)</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>Max. Input Speed (rpm)</td>
<td>4000</td>
<td>2500</td>
<td>6000</td>
<td>3600</td>
<td>4000</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>Limit for Average Input Speed (rpm)</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>Moment of Inertia (J)</td>
<td>0.033</td>
<td>0.034</td>
<td>0.135</td>
<td>0.138</td>
<td>0.36</td>
<td>0.37</td>
</tr>
</tbody>
</table>

### Notes

1. Moment of inertia: \[ I = \frac{1}{2} \pi^2 \]

2. See "Engineering data" on Page 012 for details of the terms.

---

* Torque value limited by ratcheting.

(Note)
The dimension tolerances that are not specified vary depending on the manufacturing method. Please check the confirmation drawing or contact us for dimension tolerances not shown on the drawing.

* The C, D and F₁ and F₂ values indicate relative position of individual gearing components (wave generator, flex spline, circular spline). Please strictly adhere to these values when designing your housing and mating parts.

- Four parts (wave generator, flex spline, circular spline D, circular spline S) are not assembled when delivered.
**Efficiency**

The efficiency varies depending on the following conditions.
- Reduction ratio
- Input rotational speed
- Load torque
- Temperature
- Lubrication (type and quantity)
- It looks like Graph 108-1 when the product is operated at 100% of the rated load at 40°C.

(Note) The efficiency is increased by about 10% for the grease lubrication.

![Graph 108-1](image)

**No-load running torque, starting torque, backdriving torque**

Values are based on actual tests with the component sets assembled in housings, and takes into consideration 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 40°C.

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.

![Graph 108-2](image)

**Lost motion and the spring constant**

The lost motion and the spring constant of the pancake gear is measured by fixing the wave generator and one circular spline while a torque is applied to the other circular spline.

See Page 120 for a definition of lost motion and the spring constant.

![Table 108-1](image)
**Recommended tolerances for assembly**

Maintain the recommended tolerances shown in Figure 109-1 and Table 109-1 for optimal performance.

**Precautions on installation**

- **Installation dimension precision**
  
  The concentricity and verticality against the input shaft hole of both the circular spline and the wave generator should be as follows.
  
  Concentricity: 0.03mm (T, I, R)
  
  Verticality: 0.05/100

- **Roller bearing**

  The input shaft and the output shaft should be supported by two points with an appropriate roller bearing distance and structure to bear all the radial load and axial load applied to the shaft.

- **Shaft direction stop**

  As a slight axial load is generated on the wave generator, movement in the shaft direction must be stopped.

- **Shaft direction stop of the flexspline**

  As the flexspline is disposed to move to the circular spline S side or D side during operation, a stopper should be set to prevent the flexspline from leaning.
  
  Recommended material and hardness for a stopper S45C, HRC=260 to 290 (HRC 26.4 to 29.8)

- **Fixing the circular spline (for oil lubrication)**

  Fix circular spline S. As circular spline D does not have relative rotation for the flexspline, it should be noted that the flexspline does not rotate and may not be fully lubricated if the circular spline is fixed.
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 lubricant**
     
     See Page 18 for details of the lubricant.

  2. **Oil quantity**
     
     Oil level should be maintained at the level “A” as shown. Figure 110-1.

     | Size | 14 | 20 | 25 | 32 | 40 | 50 |
     |------|----|----|----|----|----|----|
     | A    | 7  | 12 | 15 | 19 | 24 | 29 |

  3. **When to replace oil**
     
     First time .................. 100 hours after starting operation
     Second time and 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.

- **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 permissible input rotational speed in Table 106-1 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 permissible 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

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<td>016</td>
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<tr>
<td>Oil lubricant</td>
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<td>Life</td>
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<td>Starting torque</td>
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<td>Backdriving torque</td>
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<td>Efficiency</td>
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<td>&quot;dedoidal&quot; state</td>
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<td>030</td>
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<td>Checking procedure</td>
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<td>How to calculate the average load</td>
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<td>How to calculate the radial load coefficient (X)</td>
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<td>How to calculate the radial load coefficient (Y)</td>
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<td>How to calculate the life under oscillating movement</td>
<td>033</td>
</tr>
<tr>
<td>How to calculate the static safety coefficient</td>
<td>034</td>
</tr>
</tbody>
</table>
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. 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*
**Rotational direction and reduction ratio**

### Cup Style
Series: CSG, CSF, CSD, CSF-mini

#### Rotational direction

1. **Reducer**
   - Input: Wave Generator (WG)
   - Output: Flexspline (FS)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

2. **Reducer**
   - Input: Wave Generator (WG)
   - Output: Circular Spline (CS)
   - Fixed: Flexspline (FS)
   - Reduction ratio: \( R+1 \)

3. **Reducer**
   - Input: Flexspline (FS)
   - Output: Wave Generator (WG)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

4. **Overdrive**
   - Input: Circular Spline (CS)
   - Output: Flexspline (FS)
   - Fixed: Wave Generator (WG)
   - Reduction ratio: \( \frac{R+1}{R} \)

5. **Overdrive**
   - Input: Flexspline (FS)
   - Output: Wave Generator (WG)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

6. **Overdrive**
   - Input: Circular Spline (CS)
   - Output: Flexspline (FS)
   - Fixed: Wave Generator (WG)
   - Reduction ratio: \( R+1 \)

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

1. **Reducer**
   - Input: Wave Generator (WG)
   - Output: Flexspline (FS)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

2. **Reducer**
   - Input: Wave Generator (WG)
   - Output: Circular Spline (CS)
   - Fixed: Flexspline (FS)
   - Reduction ratio: \( R+1 \)

3. **Reducer**
   - Input: Flexspline (FS)
   - Output: Wave Generator (WG)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

4. **Overdrive**
   - Input: Circular Spline (CS)
   - Output: Flexspline (FS)
   - Fixed: Wave Generator (WG)
   - Reduction ratio: \( \frac{R+1}{R} \)

5. **Overdrive**
   - Input: Flexspline (FS)
   - Output: Wave Generator (WG)
   - Fixed: Circular Spline (CS)
   - Reduction ratio: \( \frac{1}{R} \)

6. **Overdrive**
   - Input: Circular Spline (CS)
   - Output: Flexspline (FS)
   - Fixed: Wave Generator (WG)
   - Reduction ratio: \( R+1 \)

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

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

Series: FB and FR

### Rotational direction

- **Input**
- **Output**

(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
   
   Reduction ratio \( i = \frac{1}{R} \)

2. **Reducer**
   - Input: Wave Generator
   - Output: Circular Spline S
   - Fixed: Circular Spline D
   
   Reduction ratio \( i = \frac{R+1}{R} \)

3. **Reducer**
   - Input: Circular Spline D
   - Output: Wave Generator
   - Fixed: Circular Spline S
   
   Reduction ratio \( i = -R \)

4. **Overdrive**
   - Input: Circular Spline S
   - Output: Circular Spline D
   - Fixed: Wave Generator
   
   Reduction ratio \( i = \frac{Z_c - Z_f}{Z_f} \)

5. **Overdrive**
   - Input: Circular Spline D
   - Output: Wave Generator
   - Fixed: Circular Spline S
   
   Reduction ratio \( i = \frac{Z_c}{Z_f} \)

6. **Overdrive**
   - Input: Circular Spline D
   - Output: Wave Generator
   - Fixed: Flexspline
   
   Reduction ratio \( i = \frac{Z_c}{Z_f} \)

7. **Differential**
   - When all of the Wave Generator, the Circular Spline D rotate, Combinations (1) through (6) are available.
   
   Reduction ratio

### 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: \( Z_f \)
- Number of teeth of the Circular Spline: \( Z_c \)

#### Example

- **Input**: Wave Generator
  - **Output**: Flexspline
  - Fixed: Circular Spline
  
  Reduction ratio \( i = \frac{1}{R_1} = \frac{Z_f - Z_c}{Z_f} \)

- **Input**: Wave Generator
  - **Output**: Flexspline
  - Fixed: Circular Spline
  
  Reduction ratio \( i = \frac{1}{R_1} = \frac{202-202}{200} = -\frac{1}{100} \)

- **Input**: Wave Generator
  - **Output**: Flexspline
  - Fixed: Flexspline
  
  Reduction ratio \( i = \frac{1}{R_2} = \frac{202-202}{202} = \frac{1}{101} \)

\( R \) indicates the reduction ratio value from the ratings table.
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 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.

**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>
<thead>
<tr>
<th>Series name</th>
<th>Life</th>
</tr>
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<tbody>
<tr>
<td>CSF, CSD, SHF, SHD, CSF-mini</td>
<td>Lₘ = 7,000 hours</td>
</tr>
<tr>
<td>CSG, SHG</td>
<td>Lₘ (average life) = 35,000 hours</td>
</tr>
</tbody>
</table>

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

**Calculation formula for Rated Lifetime** *(formula 012-1)*

\[
L_h = L_n \left( \frac{T_r}{T_{av}} \right) \cdot \left( \frac{N_r}{N_{av}} \right)
\]

**Table 012-1**

- **Life**
  - Lₘ = Life of Lₘ or Lₘ (average life)
  - T_r = Rated torque
  - N_r = Rated input speed
  - T_{av} = Average load torque on the output side *(calculation formula: Page 14)*
  - N_{av} = Average input speed *(calculation formula: Page 14)*

**Graph 012-1**

*Example of application motion profile*

**Relative torque rating** *(Graph 012-2)*

- **Buckling torque**
- **Ratcheting torque**
- **Life of wave generator (Lₘ)**
- **Fatigue strength of the flexspline**
- **Momentary peak torque**
- **Repeated peak torque**
- **Rated torque**

* 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.

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

**Calculation formula**

Caution

If the number of occurrences 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.

**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.

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.

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

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

Warning

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

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

"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.

## Flowchart for selecting a size

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

1. Review the operation conditions and model number
2. Calculate the lifetime. \[ L_{10} = 7000 \times \left( \frac{T_1}{T_{av}} \right)^{3/2} \times \frac{n_1}{n_{av}} \] (hours)
3. Check whether the calculated life is equal to or more than the life of the wave generator (see Page 13).

The model number is confirmed.

---

### Checking the application motion profile

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

**Graph 14-1**

![Graph 14-1](image)

* n1, n2 and nₙ 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** \( T_2, t_2, n_2 \)
- **Stopping (deceleration)** \( T_3, t_3, n_3 \)
- **Dwell** \( T_4, t_4, n_4 \)

#### Maximum rotational speed

- **Max. output speed** \( n_{max} \)
- **Max. input rotational speed** \( n_{i max} \)

#### Emergency stop torque

- When impact torque is applied \( T_s, t_s, n_s \)

#### Required life

- \( L_{10} = L \) (hours)
Example of model number selection

<table>
<thead>
<tr>
<th>Value of each application motion profile</th>
<th>Maximum rotational speed</th>
<th>Emergency stop torque</th>
<th>Required life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load torque</td>
<td>T1 (Nm)</td>
<td>Max. output speed</td>
<td>no max = 14 rpm</td>
</tr>
<tr>
<td>Time</td>
<td>t1 (sec)</td>
<td>Max. input speed</td>
<td>ni max = 1800 rpm</td>
</tr>
<tr>
<td>Output speed</td>
<td>n1 (rpm)</td>
<td>(Restricted by motors)</td>
<td></td>
</tr>
<tr>
<td>Normal operation pattern</td>
<td></td>
<td>When impact torque is applied</td>
<td></td>
</tr>
<tr>
<td>Starting (acceleration)</td>
<td>T1 = 400 Nm, t1 = 0.3 sec, n1 = 7 rpm</td>
<td>Ts = 500 Nm, ts = 0.15 sec, ns = 14 rpm</td>
<td></td>
</tr>
<tr>
<td>Steady operation</td>
<td>T2 = 320 Nm, t2 = 3 sec, n2 = 14 rpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(constant velocity)</td>
<td>T3 = 200 Nm, t3 = 0.4 sec, n3 = 7 rpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stopping (deceleration)</td>
<td>T4 = 0 Nm, t4 = 0.2 sec, n4 = 0 rpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwell</td>
<td></td>
<td>L10 = 7000 (hours)</td>
<td></td>
</tr>
</tbody>
</table>

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

\[
T_{av} = \frac{3}{7 \text{ rpm} \cdot 0.3 \text{ sec} \cdot |400\text{Nm}|^2 + 14 \text{ rpm} \cdot 3 \text{ sec} \cdot |320\text{Nm}| + 7 \text{ rpm} \cdot 0.4 \text{ sec} \cdot |200\text{Nm}|^2}{7 \text{ rpm} \cdot 0.3 \text{ sec} \cdot 14 \text{ rpm} \cdot 3 \text{ sec} \cdot 7 \text{ rpm} \cdot 0.4 \text{ sec}}
\]

Make a preliminary model selection with the following conditions. Tav = 319 Nm ≤ 620 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)

\[
\text{no av} = \frac{7 \text{ rpm} \cdot 0.3 \text{ sec} + 14 \text{ rpm} \cdot 3 \text{ sec} + 7 \text{ rpm} \cdot 0.4 \text{ sec}}{1800 \text{ rpm} + 14 \text{ rpm} + 120} = 12 \text{ rpm}
\]

Obtain the reduction ratio (R).

\[
\text{R} = \frac{128.6}{120} \geq 1440 \text{ rpm}
\]

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

\[
i_{av} = 12 \text{ rpm} \cdot 1440 \text{ rpm} = 1680 \text{ rpm}
\]

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

\[
i_{max} = 14 \text{ rpm} \cdot 120 = 1680 \text{ rpm}
\]

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

N1 av = 1440 rpm ≤ 3600 rpm (Max average input speed of size 40)

N1 max = 1680 rpm ≤ 5680 rpm (Max input speed of size 40)

OK

Check whether T1 and T3 are equal to or less than the repeated peak torque specification.

T1 = 400 Nm ≤ 1180 Nm (Limit of repeated peak torque of size 40)

T3 = 200 Nm ≤ 1180 Nm (Limit of repeated peak torque of size 40)

OK

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

Ts = 500 Nm ≤ 1180 Nm (Limit for momentary torque of size 40)

OK

Calculate the allowable number (Ns) rotation during impact torque and confirm ≤ 1.0\times10^4

\[
N_s = \frac{10^4}{2 \cdot 14 \text{ rpm} \cdot 120 \text{ sec} + 0.15 \text{ sec}} = 1190 \leq 1.0 \times 10^4
\]

OK

Calculate the lifetime.

\[
L_{10} = 7000 \text{ hours} \left( \frac{294 \text{ Nm} \cdot 2000 \text{ rpm}}{319 \text{ Nm} \cdot 1440 \text{ rpm}} \right)
\]

Check whether the calculated life is equal to or more than the life of the wave generator (see Page 12).

L10 = 7610 hours ≥ 7000 (life of the wave generator: L10)

OK

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

## 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. Matting 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>
<thead>
<tr>
<th>NLGI consistency No.</th>
<th>Mixing consistency range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>355 to 385</td>
</tr>
<tr>
<td>00</td>
<td>400 to 430</td>
</tr>
</tbody>
</table>

### Grease specification

<table>
<thead>
<tr>
<th>Grease</th>
<th>SK-1A</th>
<th>SK-2</th>
<th>4B No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base oil</td>
<td>Refined oil</td>
<td>Refined oil</td>
<td>Composite hydrocarbon oil</td>
</tr>
<tr>
<td>Base Viscosity @27°C</td>
<td>265 to 295</td>
<td>265 to 295</td>
<td>290 to 320</td>
</tr>
<tr>
<td>Thickening agent</td>
<td>Lithium soap base</td>
<td>Lithium soap base</td>
<td>Urea</td>
</tr>
<tr>
<td>NLGI consistency No.</td>
<td>No. 2</td>
<td>No. 2</td>
<td>No. 1.5</td>
</tr>
<tr>
<td>Additive</td>
<td>Extreme-pressure additive, others</td>
<td>Extreme-pressure additive, others</td>
<td>Extreme-pressure additive, others</td>
</tr>
<tr>
<td>Drop Point</td>
<td>197°C</td>
<td>198°C</td>
<td>247°C</td>
</tr>
<tr>
<td>Appearance</td>
<td>Yellow</td>
<td>Green</td>
<td>Light yellow</td>
</tr>
<tr>
<td>Storage life</td>
<td>5 years in sealed condition</td>
<td>5 years in sealed condition</td>
<td>5 years in sealed condition</td>
</tr>
</tbody>
</table>

### Name of lubricant

<table>
<thead>
<tr>
<th>Name of lubricant</th>
<th>Table 016-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease</td>
<td>Harmonic Grease® SK-1A</td>
</tr>
<tr>
<td></td>
<td>Harmonic Grease® SK-2</td>
</tr>
<tr>
<td>Oil</td>
<td>Industrial oil class-2 (extreme pressure) ISO VG68</td>
</tr>
</tbody>
</table>

### Temperature

<table>
<thead>
<tr>
<th>Grease</th>
<th>Table 016-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK-1A 0°C to +40°C</td>
<td>0.0°C to +40°C</td>
</tr>
<tr>
<td>SK-2   0°C to +40°C</td>
<td>0°C to +40°C</td>
</tr>
<tr>
<td>4B No.2 -10°C to +70°C</td>
<td>ISO VG68</td>
</tr>
</tbody>
</table>

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

Note: The three basic components of the gear - the Flex spline, 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.

### 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>
<thead>
<tr>
<th>Size</th>
<th>8</th>
<th>11</th>
<th>14</th>
<th>17</th>
<th>20</th>
<th>25</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK-1A</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SK-2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4B No.2</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### Ratios 50:1* and above

<table>
<thead>
<tr>
<th>Size</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>58</th>
<th>65</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK-1A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SK-2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4B No.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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

### Grease characteristics

<table>
<thead>
<tr>
<th>Grease</th>
<th>SK-1A</th>
<th>SK-2</th>
<th>4B No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fretting resistance</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Low-temperature performance</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Grease leakage</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Excellent X Good X
Use Caution X X
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: \( L_{G} = \frac{4B \text{ No.} 2}{T_{G}} \) (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

\[
L_{G} = L_{G, \text{rev}} \times \left( \frac{T_{r}}{T_{AV}} \right)^{0.3}
\]

Formula 017-1

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 contaminants 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.
- Operation range for aging: Keep the output rotational angle as large as possible. Set the speed as low as possible within the indicated range.
- The time required for aging is 20 minutes or longer.

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>
<thead>
<tr>
<th>Standard</th>
<th>Mobil Oil</th>
<th>Exxon</th>
<th>Shell</th>
<th>COSMO Oil</th>
<th>Japan Energy</th>
<th>NIPPO Oil</th>
<th>Idemitsu Kosan</th>
<th>General Oil</th>
<th>Klüber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial gear oil class-2 (extreme pressure) ISO VG68</td>
<td>Mobilgear 600XP68</td>
<td>Spartan EP68</td>
<td>Omala Oil 68</td>
<td>Cosmo gear SE68</td>
<td>ES gear G68</td>
<td>Bonock M68, Bonock AX68</td>
<td>Daphne super gear LW68</td>
<td>General Oil SP gear rol 68</td>
<td>Syntheso D-68EP</td>
</tr>
</tbody>
</table>

- 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>
<thead>
<tr>
<th>Type of lubricant</th>
<th>Operating temperature range</th>
<th>Available temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease</td>
<td>-10°C to + 110°C</td>
<td>-50°C to + 130°C</td>
</tr>
</tbody>
</table>

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.

High temperature lubricant

<table>
<thead>
<tr>
<th>Type of lubricant</th>
<th>Lubricant and manufacturer</th>
<th>Available temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease</td>
<td>Mobil grease 28: Mobil Oil</td>
<td>-5°C to + 160°C</td>
</tr>
<tr>
<td>Oil</td>
<td>Mobil SHC-626: Mobil Oil</td>
<td>-5°C to + 140°C</td>
</tr>
</tbody>
</table>

Low temperature lubricant

<table>
<thead>
<tr>
<th>Type of lubricant</th>
<th>Lubricant and manufacturer</th>
<th>Available temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease</td>
<td>Multemp SH-KII: Kyodo Oil</td>
<td>-30°C to + 50°C</td>
</tr>
<tr>
<td></td>
<td>Isoflex LDS-18 special A: KLÜBER</td>
<td>-25°C to + 80°C</td>
</tr>
<tr>
<td>Oil</td>
<td>SH-200-100CS: Toray Silicon</td>
<td>-40°C to + 140°C</td>
</tr>
<tr>
<td></td>
<td>Syntheso D-32EP: KLÜBER</td>
<td>-25°C to + 90°C</td>
</tr>
</tbody>
</table>
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 torsion almost proportional to the torque on the output side. Figure 018-1 shows the torsional angle at the output side when the torque applied on the output side starts from zero, increases up to +T0 and decreases down to −T0. 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 020-1, this “Torque – torsional angle diagram” is divided into 3 regions, and the spring constants in the area are represented by K1, K2, and K3.
  
  - K1: The spring constant when the torque changes from [zero] to [T1]
  - K2: The spring constant when the torque changes from [T1] to [T2]
  - K3: The spring constant when the torque changes from [T2] to [T3]

- **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 T1 or less, the torsion angle θ₁ is calculated as follows:
  When the load torque T₀ = 2.9 Nm
  \[ θ₁ = \frac{T₀}{K₁} \]
  \[ = \frac{2.9}{3.1 \times 10^3} \]
  \[ = 9.4 \times 10^{-4} \text{rad} \]

  When the applied torque is between T1 and T2, the torsion angle θ₂ is calculated as follows:
  When the load torque is T₂ = 39 Nm
  \[ θ₂ = θ₁ + \left( \frac{T₀ – T₂}{K₀} \right) \]
  \[ = 9.4 \times 10^{-4} + \left( \frac{39 - 14}{5.0 \times 10^3} \right) \]
  \[ = 9.4 \times 10^{-4} \text{rad} \]

  When a bidirectional load is applied, the total torsion angle will be 2 x θ₂ 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.**

  ![Spring constant diagram](image1.png)
  ![Torque - torsion angle diagram](image2.png)

- **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.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
<th>Table 021-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{er}$</td>
<td>Transmission accuracy</td>
<td></td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>Input angle</td>
<td></td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>Actual output angle</td>
<td></td>
</tr>
<tr>
<td>$R$</td>
<td>Reduction ratio</td>
<td></td>
</tr>
</tbody>
</table>

Example of measurement

![Graph 021-1]

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 $2\times$ 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.

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

The resonant frequency is generated at an input speed of 450 rpm.
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: +20°C

- 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: +20°C

- 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.

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.

Efficiency compensation coefficient

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

**Example of calculation**

Efficiency $\eta$ (%) 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 $\alpha$ is 0.58.

- The efficiency compensation coefficient is $K_e=0.93$ from Graph 023-1.
- Efficiency $\eta$ at load torque 19.6 Nm: $\eta=K_e \cdot \eta_R=0.93 \times 78=73\%$
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**

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**Fig. 025-1**
**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.
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.

![Diagram of Wave Generator](image)

(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
![Diagram of Oldham’s Coupling](image)
■ 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.)

<table>
<thead>
<tr>
<th>Size</th>
<th>8</th>
<th>11</th>
<th>14</th>
<th>17</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>58</th>
<th>65</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard dim. (H7)</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Minimum hole dim.</td>
<td>—</td>
<td>—</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>16</td>
<td>16</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Maximum hole dim.</td>
<td>—</td>
<td>—</td>
<td>8</td>
<td>10</td>
<td>13</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>37</td>
<td>40</td>
</tr>
</tbody>
</table>

Maximum hole diameter without Oldham Coupling

<table>
<thead>
<tr>
<th>Size</th>
<th>8</th>
<th>11</th>
<th>14</th>
<th>17</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>58</th>
<th>65</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. hole dia.φV</td>
<td>10</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td>28</td>
<td>36</td>
<td>42</td>
<td>47</td>
<td>52</td>
<td>60</td>
<td>67</td>
<td>72</td>
<td>84</td>
<td>95</td>
</tr>
<tr>
<td>Min. plug thick H</td>
<td>5.7</td>
<td>6.7</td>
<td>7.2</td>
<td>7.6</td>
<td>11.3</td>
<td>11.3</td>
<td>13.7</td>
<td>15.9</td>
<td>17.8</td>
<td>19</td>
<td>21.4</td>
<td>23.5</td>
<td>28.5</td>
<td>31.3</td>
<td>34.9</td>
</tr>
</tbody>
</table>

■ 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.

Calculation example

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

\[ F = \frac{382}{(32 \times 0.00254)} \times 0.07 \times \tan 30^\circ \]

\[ F = \frac{382}{(32 \times 0.00254)} \times 0.07 \times 0.58 \]

\[ F = 380 \text{ N} \]

<table>
<thead>
<tr>
<th>Reduction ratio</th>
<th>Calculation formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>( F = 2x \times 0.07 \times \tan 32^\circ )</td>
</tr>
<tr>
<td>50</td>
<td>( F = 2x \times 0.07 \times \tan 30^\circ )</td>
</tr>
<tr>
<td>80 or more</td>
<td>( F = 2x \times 0.07 \times \tan 20^\circ )</td>
</tr>
</tbody>
</table>

Symbols for Formula

- \( F \): Axial force [N]
- \( D \): Size [in]
- \( T \): Output torque [Nm]
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.

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 no 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 an 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 flexspline teeth and circular spline teeth.

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
   - 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".
   - 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. (1) Checking the maximum moment load ($M_{max}$)

| Calculate maximum moment load ($M_{max}$) | Maximum moment load ($M_{max}$) $\leq$ allowable moment ($M_c$) |

2. (2) Checking the life

| Calculate the radial load ($F_{rav}$) and the average axial load ($F_{av}$) | Calculate the radial load coefficient ($x$) and the axial load coefficient ($y$) | Calculate lifetime |

3. (3) Checking the static safety coefficient

| Calculate the static equivalent radial load coefficient ($P_o$) | Check the static safety coefficient. ($f_s$) |

How to calculate the maximum moment load

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

$M_{max} = F_{rav} \cdot (L_r+R) + F_{av} \cdot L_a$

Symbols for Formula 030-1

| $F_{rmax}$ | Max. radial load | N[kgf] | See Fig. 030-1. |
| $F_{av}$ | Max. axial load | N[kgf] | See Fig. 030-1. |
| $L_r, L_a$ | Offset amount | m | See Fig. 030-1. |
| $R$ | Offset amount | m | See Fig. 030-1 and "Specification of the output bearing" of each series. |
### 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 ($F_{rav}$)

**(Cross roller bearing)**

$$F_{rav} = \frac{n \cdot t \cdot (Lr + R)}{n \cdot t + n \cdot t_1 + \ldots + n \cdot t_n}$$

**(4-point contact ball bearing)**

$$F_{rav} = \frac{n \cdot t \cdot (Lr + R)}{n \cdot t + n \cdot t_1 + \ldots + n \cdot t_n}$$

*Note that the maximum radial load in $t$ is $F_{r1}$ and the maximum radial load in $t_3$ is $F_{r3}$.*

#### How to calculate the average axial load ($F_{av}$)

**(Cross roller bearing)**

$$F_{av} = \frac{n \cdot t \cdot (Fr + Fa)}{n \cdot t + n \cdot t_1 + \ldots + n \cdot t_n}$$

**(4-point contact ball bearing)**

$$F_{av} = \frac{n \cdot t \cdot (Fr + Fa)}{n \cdot t + n \cdot t_1 + \ldots + n \cdot t_n}$$

*Note that the maximum axial load in $t$ is $F_{a1}$ and the maximum axial load in $t_3$ is $F_{a3}$.***

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

$$N_{av} = \frac{n \cdot t + n \cdot t_1 + \ldots + n \cdot t_n}{t_1 + t_2 + \ldots + t_n}$$

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

<table>
<thead>
<tr>
<th>Formula 031-4</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{rav}$</td>
<td>&lt;=1.5</td>
<td>1</td>
</tr>
<tr>
<td>$F_{rav}/2 \cdot (Lr + R)$ + $F_{rav} \cdot La/dp$</td>
<td>&gt;1.5</td>
<td>0.67</td>
</tr>
</tbody>
</table>

#### Symbols for Formula 031-4

- $F_{rav}$: Average radial load (N(kgf))
- $F_{av}$: Average axial load (N(kgf))
- Lr, La: Offset amount (m)
- R: Pitch circle diameter of a roller (m)
- dp: See "How to calculate the average load." See Formula 031-1, Table 031-1, and "Main roller bearing specifications" 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

\[
L_{10} = \frac{10^7}{60 \times N_{av}} \times \left( \frac{C}{f_{w} \cdot P_c} \right)^{0.3}
\]

(Cross roller bearing)

(4-point contact ball bearing)

\[
L_{10} = \frac{10^7}{60 \times N_{av}} \times \left( \frac{C}{f_{w} \cdot P_c} \right)^{0.3}
\]

Formula 032-2

\[
P_c = X \cdot \left( \frac{F_{rav}}{P_c} + \frac{2(F_{rav} \cdot L_r + F_{a} \cdot L_a)}{dp} \right) + Y \cdot F_{tav}
\]

Symbols for Formula 032-2

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frav</td>
<td>Average radial load (N)</td>
</tr>
<tr>
<td>Fav</td>
<td>Average axial load (N)</td>
</tr>
<tr>
<td>dp</td>
<td>Pitch circle diameter (m)</td>
</tr>
<tr>
<td>X</td>
<td>Radial load coefficient</td>
</tr>
<tr>
<td>Y</td>
<td>Axial load coefficient</td>
</tr>
<tr>
<td>Lr, La</td>
<td>Radial load coefficient</td>
</tr>
<tr>
<td>R</td>
<td>Offset (m)</td>
</tr>
<tr>
<td>M ave</td>
<td>Average moment load (Nm)</td>
</tr>
</tbody>
</table>

Symbols for Formula 032-1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L10</td>
<td>Life (hour)</td>
</tr>
<tr>
<td>N_{av}</td>
<td>Average output rated load speed (rpm)</td>
</tr>
<tr>
<td>C</td>
<td>Basic dynamic rated load (N)</td>
</tr>
<tr>
<td>P_c</td>
<td>Dynamic equivalent load (N)</td>
</tr>
<tr>
<td>f_{w}</td>
<td>Load coefficient</td>
</tr>
</tbody>
</table>

Load status

<table>
<thead>
<tr>
<th>Load status</th>
<th>fw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady operation without impact and vibration</td>
<td>1 to 1.2</td>
</tr>
<tr>
<td>Normal operation</td>
<td>1.2 to 1.5</td>
</tr>
<tr>
<td>Operation with impact and vibration</td>
<td>1.5 to 3</td>
</tr>
</tbody>
</table>
How to calculate life during oscillating motion

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

(Cross roller bearing)
\[
L_{oc} = \frac{10^6}{60 \times n_1} \times \left( \frac{C}{f_w \cdot P_c} \right)^{0.03}
\]

(4-point contact ball bearing)
\[
L_{oc} = \frac{10^6}{60 \times n_1} \times \left( \frac{C}{f_w \cdot P_c} \right)^{0.03}
\]

Symbols for Formula 033-1

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loc</td>
<td>Rated life for oscillating motion</td>
<td>hour</td>
</tr>
<tr>
<td>n1</td>
<td>Round trip oscillation each minute</td>
<td>cpm</td>
</tr>
<tr>
<td>C</td>
<td>Basic dynamic rated load</td>
<td>N (kgf)</td>
</tr>
<tr>
<td>P_c</td>
<td>Dynamic equivalent radial load</td>
<td>N (kgf)</td>
</tr>
<tr>
<td>f_w</td>
<td>Load coefficient</td>
<td>---</td>
</tr>
<tr>
<td>θ</td>
<td>Oscillating angle /2</td>
<td>Degree</td>
</tr>
</tbody>
</table>

(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.
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.

\[
fs = \frac{Co}{Po}
\]

\[
Po = Fr_{\text{max}} + \frac{2M_{\text{max}}}{dp} + 0.44Fa_{\text{max}}
\]

Symbols for Formula 034-1

<table>
<thead>
<tr>
<th>Co</th>
<th>Basic static rated load N(kgf)</th>
<th>Po</th>
<th>Static equivalent radial load N(kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>See &quot;Specification of the output bearing&quot; of each series.</td>
<td>See Formula 034-2.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Static Safety Coefficient

<table>
<thead>
<tr>
<th>Operating condition of the roller bearing</th>
<th>fs</th>
</tr>
</thead>
<tbody>
<tr>
<td>When high rotation precision is required</td>
<td>$\geq 3$</td>
</tr>
<tr>
<td>When shock and vibration are expected</td>
<td>$\geq 2$</td>
</tr>
<tr>
<td>Under normal operating condition</td>
<td>$\leq 1.5$</td>
</tr>
</tbody>
</table>

Symbols for Formula 034-2

<table>
<thead>
<tr>
<th>Fr_{\text{max}}</th>
<th>Max. radial load N(kgf)</th>
<th>M_{\text{max}}</th>
<th>Max. moment load Nm(kgf/m)</th>
<th>See &quot;Specification of the output bearing&quot; of each series.</th>
</tr>
</thead>
<tbody>
<tr>
<td>See &quot;How to calculate the maximum moment load&quot; on Page 030.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dp</th>
<th>Pitch circle diameter of a roller m</th>
<th>See Fig. 030-1 and &quot;Specification of the output bearing&quot; of each series.</th>
</tr>
</thead>
</table>
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