Engineering Data
SHG-2A Component Sets

Harmonic
Drive AG

Contents

1. General

About this documentation

This document contains safety instructions, technical data and operation rules for products of Harmonic Drive AG.
The documentation is aimed at planners, project engineers, commissioning engineers and machine manufacturers, offering support during selection and calculation of the servo actuators, servo motors and accessories.

Rules for storage

Please keep this document for the entire life of the product, up to its disposal. Please hand over the documentation when re-selling the product.

Additional documentation

For the configuration of drive systems using the products of Harmonic Drive AG, you may require additional documents. Documentation is provided for all products offered by Harmonic Drive AG and can be found in pdf format on the website.

www.harmonicdrive.de

Third-party systems

Documentation for parts supplied by third party suppliers, associated with Harmonic Drive® components, is not included in our standard documentation and should be requested directly from the manufacturers.

Before commissioning products from Harmonic Drive AG with servo drives, we advise you to obtain the relevant documents for each device.

Your feedback

Your experiences are important to us. Please send suggestions and comments about the products and documentation to:

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Marketing and Communications
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65555 Limburg / Lahn
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E-Mail: info@harmonicdrive.de

1.1 Description of Safety Alert Symbols

Symbol	Meaning
⚠ DANGER	Indicates an imminent hazardous situation. If this is not avoided, death or serious injury could occur.
⚠ WARNING	Indicates a possible hazard. Care should be taken or death or serious injury may result.
⚠ ATTENTION	Indicates a possible hazard. Care should be taken or slight or minor injury may result.
ADVICE	Describes a possibly harmful situation. Care should be taken to avoid damage to the system and surroundings.
INFORMATION	This is not a safety symbol. This symbol indicates important information.
⚠	Warning of a general hazard. The type of hazard is determined by the specific warning text.
⚡	Warning of dangerous electrical voltage and its effects.
♨	Beware of hot surfaces.
⚠	Beware of suspended loads.
⚠	Precautions when handling electrostatic sensitive components.

1.2 Disclaimer and Copyright

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We have checked the contents of this document. Since errors cannot be ruled out entirely, we do not accept liability for mistakes which may have occurred. Notification of any mistake or suggestions for improvements will be gratefully received and any necessary correction will be included in subsequent editions.

2. Safety and Installation Instructions

Please take note of the information and instructions in this document. Specialy designed models may differ in technical detail. If in doubt, we strong recommend that you contact the manufacturer, giving the type designation and serial number for clarification.

2.1 Hazards

 DANGER

Electric products have dangerous live and redating parts. All work during connection, operation, repair and disposal must be carried out by qualified personnel as described in the standards EN50110-1 and IEC 60364! Before starting any work, and especially before opening covers, the actuator must be properly isolated. In addition to the main circuits, the user also has to pay attention to any auxilliary circuits.

Observing the five safety rules:
• Disconnect mains
• Prevent reconnection
• Test for absence of harmful voltages
• Ground and short circuit
• Cover or close off nearby live parts

The measures taken above must only be withdrawn when the work has been completed and the device is fully assembled. Improper handling can cause damage to persons and property. The respective national, local and factory specific regulations must be adhered to.

 DANGER

Electric, magnetic and electromagnetic fields are dangerous, in particular for persons with pacemakers, implants or similiar. Vulnerable groups must not be in the immediate vicinity of the products themselves.

 DANGER

Built-in holding brakes alone are not functional safe. Particularly with unsupported vertical axes, the functional safety and security can only be achieved with additional, external mechanical brakes.

 WARNING

The successful and safe operation of gears, products requires proper transport, storage and assembly as well as correct operation and maintenance.

 ATTENTION

The surface temperature of gears, motors and actuators can exceed 55 degrees Celsius. The hot surfaces should not be touched.

Movement and lifting of products with a mass > 20 Kg should only be carried out with suitable lifting gear.

Cables must not come into direct contact with hot surfaces.

Special versions of drive systems and motors may have differing specifications. Please consider all data sheet, catalogues and offers etc. sent concerning these special versions.

2.2 Intended Purpose

The Harmonic Drive® products are intended for industrial or commercial applications. They comply with the relevant parts of the harmonised EN 60034 standards series.

Typical areas of application are robotics and handling, machine tools, packaging and food machines and similar machines.

The products may only be operated within the operating ranges and environmental conditions shown in the documentation (altitude, degree of predection, temperature range etc).
Before plant and machinery which have Harmonic Drive® products built into them are commissioned, the compliance must be established with the Machinery Directive, Low Voltage Directive and EMC guidelines.

Plant and machinery with inverter driven motors must satisfy the predection requirements in the EMC guidelines. It is the responsibility of the installer to ensure that installation is undertaken correctly.
Signal and power lines must be shielded. The EMC instructions from the inverter manufacturer must be observed in order that installation meets the EMC regulations.

2.3 Non Intended Purpose

The use of products outside the areas of application mentioned above or, inter alia, other than in the operating areas or environmental conditions described in the documentation is considered as non-intended purpose.

The following areas of application are, inter alia, those considered as non-intended purpose:

• Aerospace
• Areas at risk of explosion
• Machines specially constructed or used for a nuclear purpose whose breakdown might lead to the emission of radio-activity
• Vacuum
• Machines for domestic use
• Medical equipment which comes into direct contact with the human body
• Machines or equipment for transporting or lifting people
• Special devices for use in annual markets or leisure parks

2.4 Declaration of Conformity

Harmonic Drive® gears are components for installation in machines as defined by the machine directive 89/392/EWG. Commissioning is prohibited until such time as the end product has been proved to conform to the provisions of this directive.

Essential health and safety requirements were considered in the design and manufacture of these gear component sets. This simplifies the implementation of the machinery directive by the end user for the machinery or the partly completed machinery. Commissioning of the machine or partly completed machine is prohibited until the final product conforms to the EC Machinery Directive.

3. Technical Description

3.1 Product Description

Compact with largest hollow shaft

SHG-2A Series Component Sets are available in ten sizes with gear ratios of 50, 80, 100, 120 and 160:1 offering repeatable peak torques from 23 to 3419 Nm.

If required, the Component Sets are available as specific configurations tailored to your application, including special lubricants for extended temperature ranges or special materials for extreme ambient conditions. Consisting of just three individual components, they are very lightweight and compact.

The enlarged hollow shaft can be used to feed through supply lines, shafts or cables for further axes. Due to their positioning accuracy stable machine properties with short cycle times are guaranteed.

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3.2 Ordering Code

Table 9.1

Series	Size	Ratio [1]					Version	Special design
SHG	14	50	80	100			2A-GR	According to customer requirements
	17	50	80	100	120			
	20	50	80	100	120	160		
	25	50	80	100	120	160		
	32	50	80	100	120	160		
	40	50	80	100	120	160		
	45	50	80	100	120	160		
	50	–	80	100	120	160		
	58	–	80	100	120	160		
	65	–	80	100	120	160		

Bestellbezeichnung								
SHG	**-**	**25**	**-**	**100**	**-**	**2A-GR**	**-**	**SP**

[1] The ratios shown here are for a standard driving configuration with the circular spline fixed, the Wave Generator used for the input and the Flexspline attached to the output. Other configurations are possible. Please consult chapter 4 "Ratio".

3.3 Technical Data

3.3.1 General Technical Data

Table 10.1

	Unit	SHG-14-2A			SHG-17-2A			
Ratio	i [ ]	50	80	100	50	80	100	120
Repeatable peak torque	T_R [Nm]	23	30	36	44	56	70	70
Average torque	T_A [Nm]	9.0	14	14	34	35	51	51
Rated torque	T_N [Nm]	7.0	10	10	21	29	31	31
Momentary peak torque	T_M [Nm]	46	61	70	91	113	143	112
Maximum input speed (Oil Lubrication)	$n_{in (max)}$ [rpm]	14000			10000			
Maximum input speed (Grease Lubrication)	$n_{in (max)}$ [rpm]	8500			7300			
Average input speed (Oil Lubrication)	$n_{av (max)}$ [rpm]	6500			6500			
Average input speed (Grease Lubrication)	$n_{av (max)}$ [rpm]	3500			3500			
Moment of inertia	J_{in} [x10^{-4} kgm^2]	0.033			0.079			
Weight	m [kg]	0.11			0.18			

Table 10.2

	Unit	SHG-20-2A					SHG-25-2A				
Ratio	i [ ]	50	80	100	120	160	50	80	100	120	160
Repeatable peak torque	T_R [Nm]	73	96	107	113	120	127	178	204	217	229
Average torque	T_A [Nm]	44	61	64	64	64	72	113	140	140	140
Rated torque	T_N [Nm]	33	44	52	52	52	51	82	87	87	87
Momentary peak torque	T_M [Nm]	127	165	191	191	191	242	332	369	395	408
Maximum input speed (Oil Lubrication)	$n_{in (max)}$ [rpm]	10000					7500				
Maximum input speed (Grease Lubrication)	$n_{in (max)}$ [rpm]	6500					5600				
Average input speed (Oil Lubrication)	$n_{av (max)}$ [rpm]	6500					5600				
Average input speed (Grease Lubrication)	$n_{av (max)}$ [rpm]	3500					3500				
Moment of inertia	J_{in} [x10^{-4} kgm^2]	0.193					0.413				
Weight	m [kg]	0.31					0.48				

3.3.2 Dimensions

Illustration 11.1   SHG-14-2A   [mm]
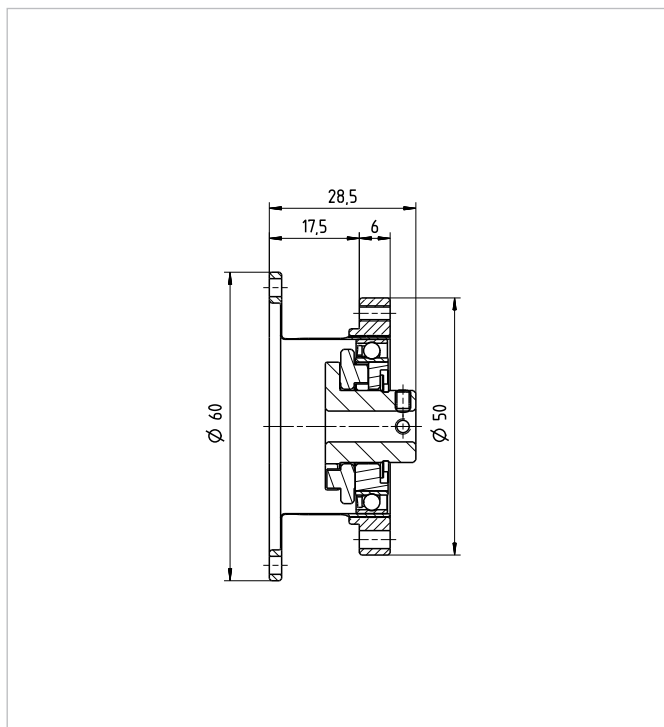

Illustration 11.2   SHG-17-2A   [mm]

Illustration 11.3   SHG-20-2A   [mm]
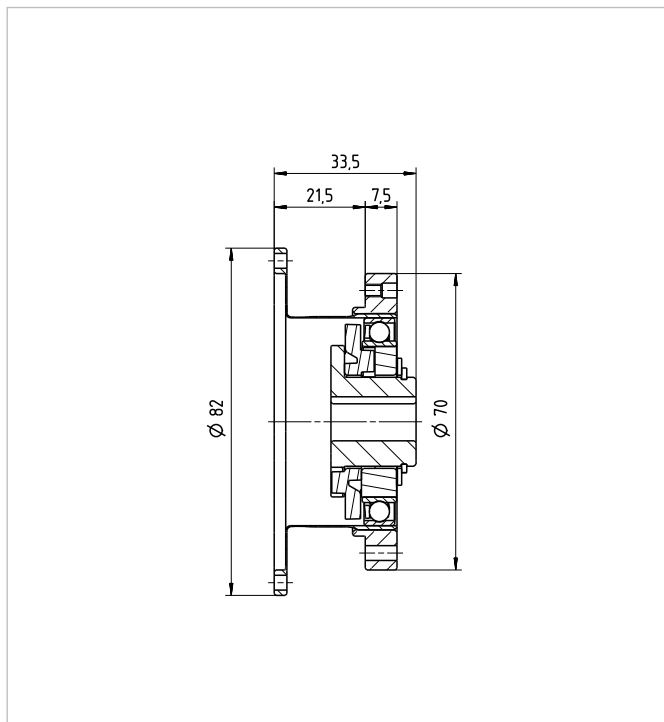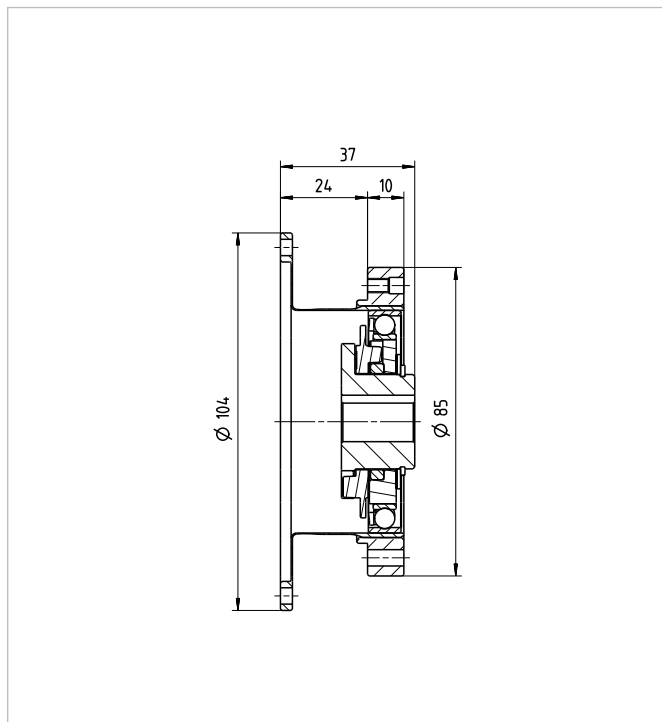

Illustration 11.4   SHG-25-2A   [mm]

Table 12.1

	Unit	SHG-32-2A					SHG-40-2A				
Ratio	i [ ]	50	80	100	120	160	50	80	100	120	160
Repeatable peak torque	T_R [Nm]	281	395	433	459	484	523	675	738	802	841
Average torque	T_A [Nm]	140	217	281	281	281	255	369	484	586	586
Rated torque	T_N [Nm]	99	153	178	178	178	178	268	345	382	382
Kollisionsdrehmoment	T_M [Nm]	497	738	841	892	892	892	1270	1400	1530	1530
Maximum input speed (Oil Lubrication)	$n_{in(max)}$ [rpm]	7000					5600				
Maximum input speed (Grease Lubrication)	$n_{in(max)}$ [rpm]	4800					4000				
Average input speed (Oil Lubrication)	$n_{av(max)}$ [rpm]	4600					3600				
Average input speed (Grease Lubrication)	$n_{av(max)}$ [rpm]	3500					3000				
Moment of inertia	J_{in} [x10^{-4} kgm²]	1.69					4.5				
Weight	m [kg]	0.89					1.86				

Table 12.2

	Unit	SHG-45-2A					SHG-50-2A			
Ratio	i [ ]	50	80	100	120	160	80	100	120	160
Repeatable peak torque	T_R [Nm]	650	918	982	1070	1147	1223	1274	1404	1534
Average torque	T_A [Nm]	345	507	650	806	819	675	866	1057	1096
Rated torque	T_N [Nm]	229	407	452	523	523	484	611	688	688
Momentary peak torque	T_M [Nm]	1235	1651	2041	2288	2483	2418	2678	2678	3185
Maximum input speed (Oil Lubrication)	$n_{in(max)}$ [rpm]	5000					4500			
Maximum input speed (Grease Lubrication)	$n_{in(max)}$ [rpm]	3800					3500			
Average input speed (Oil Lubrication)	$n_{av(max)}$ [rpm]	3300					3000			
Average input speed (Grease Lubrication)	$n_{av(max)}$ [rpm]	3000					2500			
Moment of inertia	J_{in} [x10^{-4} kgm²]	8.68					12.5			
Weight	m [kg]	2.64					3.53			

Illustration 13.1   HFUS-32-2A   [mm]

Illustration 13.2   HFUS-40-2A   [mm]

Illustration 13.3   HFUS-45-2A   [mm]

Illustration 13.4   HFUS-50-2A   [mm]

QUICKLINK
www.harmonicdrive.de/CAD3070

Table 14.1

	Unit	SHG-58-2A				SHG-65-2A			
Ratio	i [ ]	80	100	120	160	80	100	120	160
Repeatable peak torque	T_R [Nm]	1924	2067	2236	2392	2743	2990	3263	3419
Average torque	T_A [Nm]	1001	1378	1547	1573	1352	1976	2041	2041
Rated torque	T_N [Nm]	714	905	969	969	969	1236	1236	1236
Momentary peak torque	T_M [Nm]	3185	4134	4329	4459	4836	6175	6175	6175
Maximum input speed (Oil Lubrication)	$n_{in\,(max)}$ [rpm]	4000				3500			
Maximum input speed (Grease Lubrication)	$n_{in\,(max)}$ [rpm]	3000				2800			
Average input speed (Oil Lubrication)	$n_{av\,(max)}$ [rpm]	2700				2400			
Average input speed (Grease Lubrication)	$n_{av\,(max)}$ [rpm]	2200				1900			
Moment of inertia	J_{in} [x10^{-4} kgm^2]	27.3				46.5			
Weight	m [kg]	5.17				7.04			

Illustration 14.2   SHG-58-2A [mm]

Illustration 14.3   SHG-65-2A [mm]

QUICKLINK
www.harmonicdrive.de/CAD3050

3.3.3 Minimum Housing Clearance

Table 15.1 [mm]

Size	14	17	20	25	32	40	45	50	58	65
u	1.7	2.1	2.0	2.0	2.0	2.0	2.3	2.5	2.9	3.5
∅W	31	38	45	56	73	90	101	113	131	150
x	24.5	27.5	30.5	35.5	43.5	53.0	59.0	65.0	75.5	84.0
y	2.9	3.6	3.7	4.2	4.8	5.4	6.1	6.8	7.9	9.5
∅Z	38	45	53	66	86	106	119	133	154	172

Illustration 15.2

3.3.4 Accuracy

Table 15.3 [arcmin]

Size	14	17	≥20
Ratio	≥50	≥50	≥50
Transmission accuracy[1]	<1,5	<1,5	<1
Hysteresis loss	<1	<1	<1
Lost Motion		<1	
Repeatability		< ± 0,1	

[1] Higher precision on request

3.3.5 Torsional Stiffness

Table 15.4

Size		14	17	20	25	32	40	45	50	58	65
T_1 [Nm]		2	3,9	7	14	29	54	76	108	168	235
T_2 [Nm]		6.9	12	25	48	108	196	275	382	598	843
i = 30	K_3 [x10³ Nm/rad]	3.4	6.7	11	21	49	–	–	–	–	–
	K_2 [x10³ Nm/rad]	2.4	4.4	7.1	13	30	–	–	–	–	–
	K_1 [x10³ Nm/rad]	1.9	3.4	5.7	10	24	–	–	–	–	–
i = 50	K_3 [x10³ Nm/rad]	5.7	13	23	44	98	180	260	340	540	–
	K_2 [x10³ Nm/rad]	4.7	11	18	34	78	140	200	280	440	–
	K_1 [x10³ Nm/rad]	3.4	8.1	13	25	54	100	150	200	310	–
i > 50	K_3 [x10³ Nm/rad]	7.1	16	29	57	120	230	330	440	710	980
	K_2 [x10³ Nm/rad]	6.1	14	25	50	110	200	290	400	610	880
	K_1 [x10³ Nm/rad]	4.7	10	16	31	67	130	180	250	400	540

4. Driving Arrangements

A variety of different driving arrangements are possible with Harmonic Drive® gears.

Equation 16.1

$$\text{Ratio } i = \frac{\text{Input speed}}{\text{Output speed}}$$

Overview Harmonic Drive® Products

The three main components of the Harmonic Drive® units, Circular Spline (CS), Flexspline (FS) and Wave Generator (WG) can be seen in the illustration 16.2.

Illustration 16.2

The values for ratios of Harmonic Drive® gears refer to the standard input and output arrangement (example 1 in the table below). Other arrangements are possible, and also shown in the table.

Ratio

1)

Reduction gearing
- CS   Fixed
- WG   Input
- FS   Output

Equation 17.1

$$\text{Ratio} = -\frac{i}{1}$$

Input and output rotate in opposite directions.

2)

Reduction gearing
- FS   Fixed
- WG   Input
- CS   Output

Equation 17.2

$$\text{Ratio} = \frac{i+1}{1}$$

Input and output rotate in same direction.

3)

Reduction gearing
- WG   Fixed
- FS   Input
- CS   Output

Equation 17.3

$$\text{Ratio} = \frac{i+1}{i}$$

Input and output rotate in same direction.

4)

Speed increaser gearing
- WG   Fixed
- CS   Input
- FS   Output

Equation 17.4

$$\text{Ratio} = \frac{i}{i+1}$$

Input and output rotate in same direction.

5)

Speed increaser gearing
- CS   Fixed
- FS   Input
- WG   Output

Equation 17.5

$$\text{Ratio} = -\frac{1}{i}$$

Input and output rotate in opposite directions.

6)

Speed increaser gearing
- FS   Fixed
- CS   Input
- WG   Output

Equation 17.6

$$\text{Ratio} = \frac{1}{i+1}$$

Input and output rotate in same direction.

7)

Differential gear
- WG   Control input
- CS   Main drive input
- FS   Main drive output

Numerous differential functions can be obtained by combinations of the speed and rotational direction of the three basic elements.
Please refer to our broshure "Differential Applications" available to download from our website.

4.1 Selecting Harmonic Drive® Gears

When choosing a gear, both torque as well as stiffness requirements should be take into account. In robot applications, for example, the necessary torque is the more crucial factor for the gear size, while the torsional stiffness is often decisive in machine tool applications. We therefore recommend that you always take both criteria into account according to the following procedures.

<div style="background-color:#1ba0d7; color:white; display:inline-block; padding:4px 40px 4px 8px;">ADVICE</div>

We will be pleased to make a gear calculation and selection on your behalf. Please contact our application engineers.

```
                    ┌─────────────────────┐
                    │     Application     │
                    └─────────────────────┘
                              │
                              ▼
                    ┌─────────────────────┐
                    │  Gear preselection  │
                    └─────────────────────┘
                              │
                              ▼
                    ┌─────────────────────┐
                    │ Torque based        │
                    │ dimensioning        │
                    │ according to        │
                    │ selection           │          ┌──────────────┐
                    │ procedure on page 19│          │ Selection of │
                    └─────────────────────┘          │ a bigger size│
                              │                       └──────────────┘
                              ▼
                        ╱─────────╲
                Yes    ╱ Gear size  ╲   No
              ◄───────╱  sufficient? ╲───────►
                       ╲            ╱
                        ╲──────────╱
                              │
                              ▼
                    ┌─────────────────────┐
                    │ Stiffness based     │
                    │ dimensioning        │
                    │ according to        │
                    │ selection           │          ┌──────────────┐
                    │ procedure on page 22│          │ Selection of │
                    └─────────────────────┘          │ a bigger size│
                              │                       └──────────────┘
                              ▼
                        ╱─────────╲
                Yes    ╱ Gear size  ╲   No
              ◄───────╱  sufficient? ╲───────►
                       ╲            ╱
                        ╲──────────╱
                              │
                              ▼
                    ┌─────────────────────┐
                    │   End of gear       │
                    │   selection         │
                    └─────────────────────┘
```

4.1.1 Torque Based Dimensioning

Output Data

Torques	$T_1...T_n$	[Nm]
during the load phases	$t_1...t_n$	[s]
during the pause time	t_p	[s]
and output speeds	$n_1...n_n$	[rpm]
Emergency stop/momentary peak torque	T_k	[Nm]
at output speed	n_k	[rpm]
and duration	t_k	[s]

Illustration 19.1

Equation 19.2

Load limit 1,
Calculation of the average output torque T_{av}

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

Equation 19.3

Values for T_A see rating tables
$T_{av} \leq T_A$

No → Selection of a bigger size

Equation 19.4

Calculation of the average output speed

$$n_{out\,av} = \frac{|n_1| \cdot t_1 + |n_2| \cdot t_2 + ... + |n_n| \cdot t_n}{t_1 + t_2 + ... + t_n + t_p}$$

Equation 19.5

Average input speed
$$n_{in\,av} = i \cdot n_{out\,av}$$

Equation 19.6

Permissible maximum input speed

$n_{in\,max} = n_{out\,max} \cdot i \leq$ Maximum input speed (see rating table)

Equation 19.7

Permissible average input speed
$n_{in\,av} \leq$ Limit for average input speed
(see rating table)

Equation 19.8

Load limit 2, T_R

$T_{max} \leq T_R$

Equation 19.9

Load limit 3, T_M

$T_k \leq T_M$

Equation 19.10

Allowable number of momentary peak torques

$$N_{k\,max} = \frac{10^4}{2 \cdot \frac{n_k}{60} \cdot i \cdot t_k} < 10^4$$

Equation 19.11

Operating life

$$L_{50} = L_n^* \cdot \frac{\text{Rated input speed}}{n_{in\,av}} \cdot \left(\frac{\text{Rated torque } T_N}{T_{av}} \right)^3$$
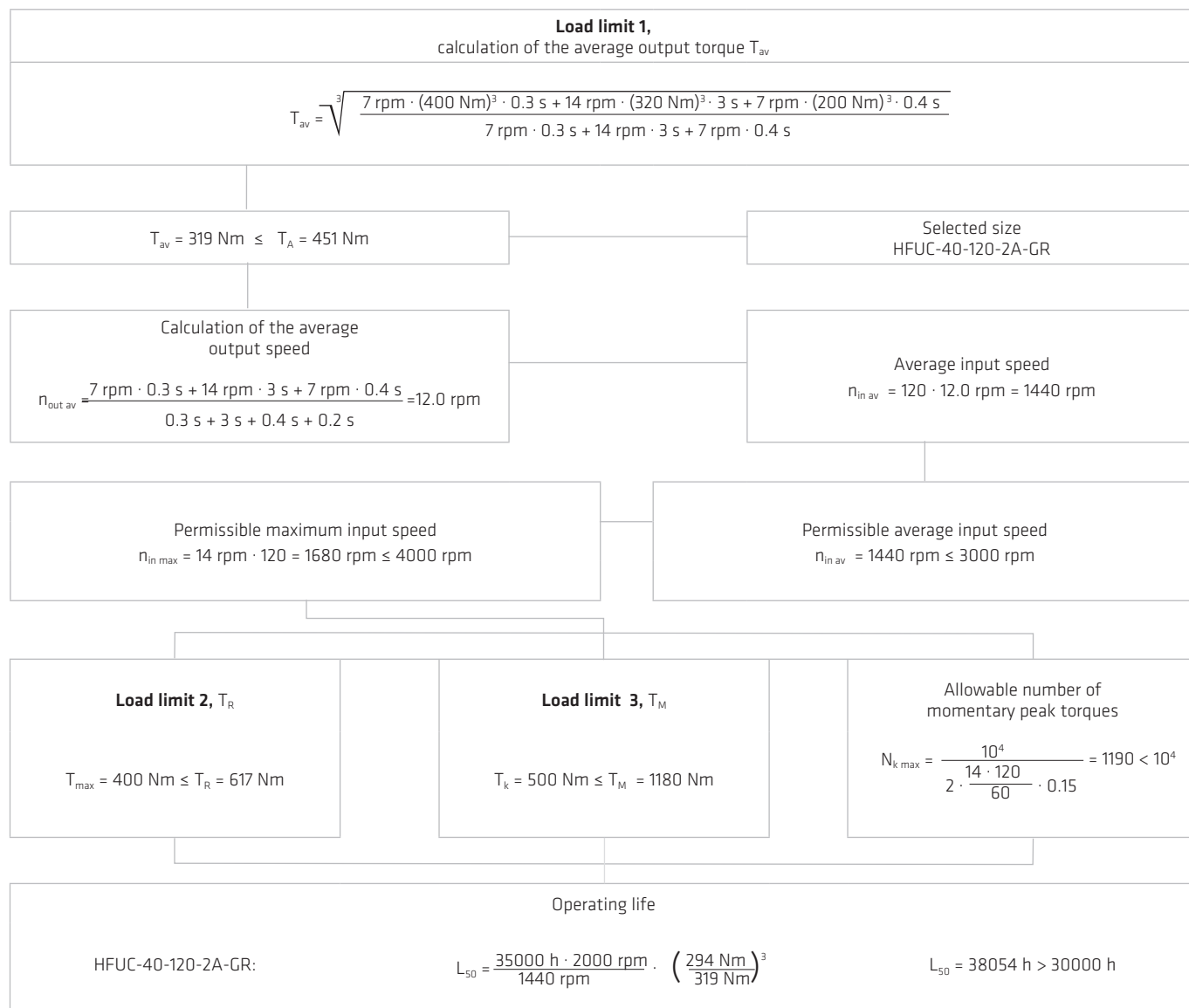
Values for L_n see table 21.1

Output Data

$T_1 =$ 400 Nm	$t_1 =$ 0.3 s	$n_1 =$ 7 rpm
$T_2 =$ 320 Nm	$t_2 =$ 3.0 s	$n_2 =$ 14 rpm
$T_3 =$ 200 Nm	$t_3 =$ 0.4 s	$n_3 =$ 7 rpm
$T_k =$ 500 Nm	$t_k =$ 0.15 s	$n_k =$ 14 rpm
	$t_p =$ 0.2 s	$n_p =$ 0 rpm

Ratio i = 120
Life L_{50} = 30000 h (required)

Load limit 1,
calculation of the average output torque T_{av}

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

T_{av} = 319 Nm ≤ T_A = 451 Nm

Selected size
HFUC-40-120-2A-GR

Calculation of the average
output speed

$$n_{out\ av} = \frac{7\ \text{rpm} \cdot 0.3\ \text{s} + 14\ \text{rpm} \cdot 3\ \text{s} + 7\ \text{rpm} \cdot 0.4\ \text{s}}{0.3\ \text{s} + 3\ \text{s} + 0.4\ \text{s} + 0.2\ \text{s}} = 12.0\ \text{rpm}$$

Average input speed
$n_{in\ av}$ = 120 · 12.0 rpm = 1440 rpm

Permissible maximum input speed
$n_{in\ max}$ = 14 rpm · 120 = 1680 rpm ≤ 4000 rpm

Permissible average input speed
$n_{in\ av}$ = 1440 rpm ≤ 3000 rpm

Load limit 2, T_R

T_{max} = 400 Nm ≤ T_R = 617 Nm

Load limit 3, T_M

T_k = 500 Nm ≤ T_M = 1180 Nm

Allowable number of
momentary peak torques

$$N_{k\ max} = \frac{10^4}{2 \cdot \dfrac{14 \cdot 120}{60} \cdot 0.15} = 1190 < 10^4$$

Operating life

HFUC-40-120-2A-GR:
$$L_{50} = \frac{35000\ \text{h} \cdot 2000\ \text{rpm}}{1440\ \text{rpm}} \cdot \left(\frac{294\ \text{Nm}}{319\ \text{Nm}}\right)^3$$
L_{50} = 38054 h > 30000 h

4.1.2 Life of the Wave Generator Bearing

Given that the Harmonic Drive® Gear is rated to provide infinite fatigue life for the Flexspline, the life expectancy is based on the average life of the Wave Generator bearing. The rated torque at the rated speed given in the rating table is based on the mean L_{50} bearing life.

The life expectancy of a component set or an unit operating at an input speed n (rpm) and output torque T (Nm) may be estimated from equation 21.2.

Table 21.1   [h]

Harmonic Drive® series	L_n
CobaltLine, CSG, SHG	50000
HFUC, HFUS, CSD, CPU, CSF, SHD	35000
PMG gearbox	15000

Equation 21.2

$$L_{50} = L_n \frac{n_N}{n_{in\ av}} \left(\frac{T_N}{T_{av}}\right)^3$$

Equation 21.3

$$L_{10} \approx \frac{1}{5} \cdot L_{50}$$

n_N = Rated input speed [rpm]
$n_{in\ av}$ = Average input speed [rpm] (equation 19.5)
T_N = Rated output torque at rated speed [Nm]
T_{av} = Average output torque [Nm] (equation 19.2)
L_n = See table 21.1

4.1.3 Stiffness Based Dimensioning

In addition to the "Torque Based Dimensioning" stated on page 19, we recommend that you carry out a selection based on stiffness. For this, the values provided in table 22.1 for the individual resonance frequencies recommended for each application should be taken into account.

Table 22.1   [Hz]

Application	f_n
Slowly rotating turntables, base axes of slow moving welding robots (not laser welding), slowly rotating welding and swinging tables, gantry robot axes	≥ 4
Base axes of revolute robots, hand axes of revolute robots with low requirements regarding dynamic perfomance, tool revolvers, tool magazines, swivelling and positioning axes in medical and measuring devices	≥ 8
Standard applications in general mechanical engineering, tilting axes, palette changers, highly dynamic tool changers, revolvers and magazines, hand axes of robots, scara robots, gantry robots, polishing robots, dynamic welding manipuators, base axes of welding robots (laser welding), swivelling and positioning axes of medical equipment	≥ 15
B/C axes in 5 axis grinding machines, hand axes of welding robots (laser welding), milling heads for plastics machining	≥ 20
C axes in turning machines, milling heads for light metal machining, milling heads for woodworking (chipboards etc.)	≥ 25
Milling heads for woodworking (hardwood etc.)	≥ 30
C axes in turning machines*	≥ 35
Milling heads for metal machining*, B axes in turning milling centers for metal machining	≥ 40
Milling heads for metal machining*, B axes in turning milling centers for metal machining with high requirements regarding surface quality*	≥ 50
Milling heads for metal machining with very high requirements regarding surface quality*	≥ 60

* Depending on the application, a secondary gear stage may be useful. Please contact Harmonic Drive AG for more information.

Selection Example: Stiffness Based Dimensioning

Resonance Frequency (Gear Output)

The formula

Equation 23.1

$$f_n = \frac{1}{2\pi} \sqrt{\frac{K_1}{J}} \ [Hz]$$

f_n = Resonance frequency [Hz]
K_1 = Gear torsional stiffness K_1 [Nm/rad]
J = Load moment of inertia [kgm^2]

allows the calculation of the resonance frequency at the gear output from the given torsional stiffness, K_1, of the Harmonic Drive® gear and the load's moment of inertia. The calculated frequency should correspond with the value provided in table 22.1. The higher the load's moment of inertia, the more influence the application has on the gear selection. If the moment of inertia = 0, the selected application has no numerical influence on the selection result.

Resonance Speed (Gear Input)

The resonance speed n_n on the input side (motor side) can be calculated using the formula

$n_n = f_n \cdot 30$ [rpm]

During operation, we recommend that you pass the resonance speed rapidly. This can be achieved by selecting a suitable gear ratio. Another possibility is to select suitable gear stiffness such that the resonance speed lies
beyond the required speed range.

Selection Example

HFUC-40-120-2A-GR preselected from "Selection Procedure" on page 20.

Intended application: milling head for woodworking
Moment of inertia at the gear output: 7 kgm^2. Recommended resonance frequency from table 22.1: ≥ 30 Hz.
Resonance frequency using the preselected gear
HFUC-40-120-2A-GR:

$$f_n = \frac{1}{2\pi} \cdot \sqrt{\frac{1.3 \cdot 10^5}{7}} = 22 \ [Hz]$$

According to stiffness based dimensioning, this gear size is too small for the application.
The larger gear HFUC-50-120-2A-GR results in a resonance frequency of:

$$f_n = \frac{1}{2\pi} \cdot \sqrt{\frac{2.5 \cdot 10^5}{7}} = 30 \ [Hz]$$

Based on stiffness based dimensioning, the gear HFUC-50-120-2A-GR is recommended.

The resonance speed at the input (motor) amounts to:
$n_n = 30 \cdot 30 = 900$ [rpm]

Either, this speed should be passed without stopping when accelerating / braking, or it should
lie beyond the utilised speed range.

4.2 Calculation of the Torsion Angle

Calculation of the Torsion Angle φ at Torque T:

Equation 24.1

$$T \leq T_1$$

$$\varphi = \frac{T}{K_1}$$

Equation 24.2

$$T_1 < T \leq T_2$$

$$\varphi = \frac{T_1}{K_1} + \frac{T - T_1}{K_2}$$

Equation 24.3

$$T > T_2$$

$$\varphi = \frac{T_1}{K_1} + \frac{T_2 - T_1}{K_2} + \frac{T - T_2}{K_3}$$

φ = Angle [rad]
T_1 = Limit torque 1 from Section 3.3.5 [Nm]
T_2 = Limit torque 2 from Section 3.3.5 [Nm]
K_1 = Torsional stiffness up to the limit torque T_1 from Section 3.3.5 [Nm/rad]
K_2 = Torsional stiffness up to the limit torque T_2 from Section 3.3.5 [Nm/rad]
K_3 = Torsional stiffness above the limit torque T_2 from Section 3.3.5 [Nm/rad]

Example: HFUC-32-100-2UH

T = 60 Nm K_1 = 6.7 · 10⁴ Nm/rad

T_1 = 29 Nm K_2 = 1.1 · 10⁵ Nm/rad

T_2 = 108 Nm K_3 = 1.2 · 10⁵ Nm/rad

$$\varphi = \frac{29 \text{ Nm}}{6.7 \cdot 10^4 \text{ Nm/rad}} + \frac{60 \text{ Nm} - 29 \text{ Nm}}{11 \cdot 10^4 \text{ Nm/rad}}$$

$$\varphi = 7.15 \cdot 10^{-4} \text{ rad}$$

$$\varphi = 2.5 \text{ arc min}$$

Equation 24.4

$$\varphi \text{ [arc min]} = \varphi \text{ [rad]} \cdot \frac{180 \cdot 60}{\pi}$$

4.3 Accuracy of the Oldham Coupling

Information concerning the Oldham coupling can be found in section 5.5.

In the region of tooth engagement Harmonic Drive® gears have no backlash. If an Oldham coupling is used for the compensation of eccentricity errors of the motor shaft, a small backlash in the range of a few seconds of arc can occur at the output shaft, as listed in table 24.5.

Table 24.5   [arcsec]

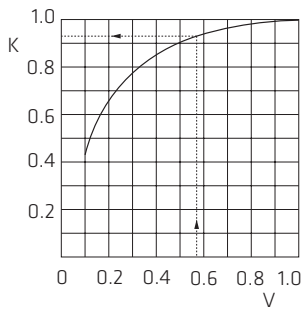| Size		14	17	20	25	32	40	45	50	58	65
	50	36	20	17	17	14	14	12	12	10	10
	80	23	13	11	11	9	9	8	8	6	6
Ratio	100	18	10	9	9	7	7	6	6	5	5
	120	–	8	8	8	6	6	5	5	4	4
	160	–	–	6	6	5	5	4	4	3	3

4.4 Efficiency Versus Load

Efficiency for Harmonic Drive® Gears varies depending on the output torque. The efficiency curves are for gears operating at rated output torque. Efficiency for a gear operating at a load below the rated torque may be estimated using a compensation curve and equation as shown on the next page.
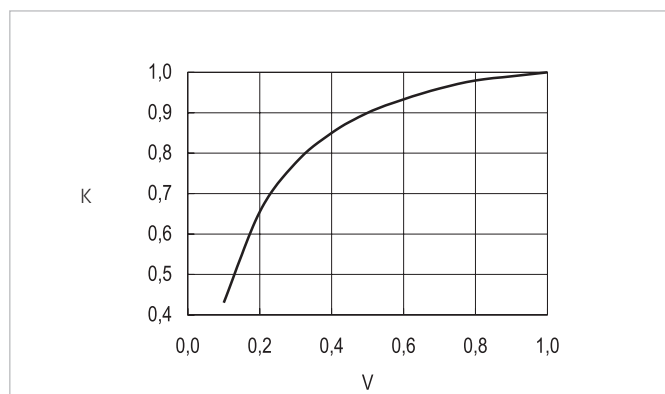
4.4.1 Efficiency Calculations

Table 25.1

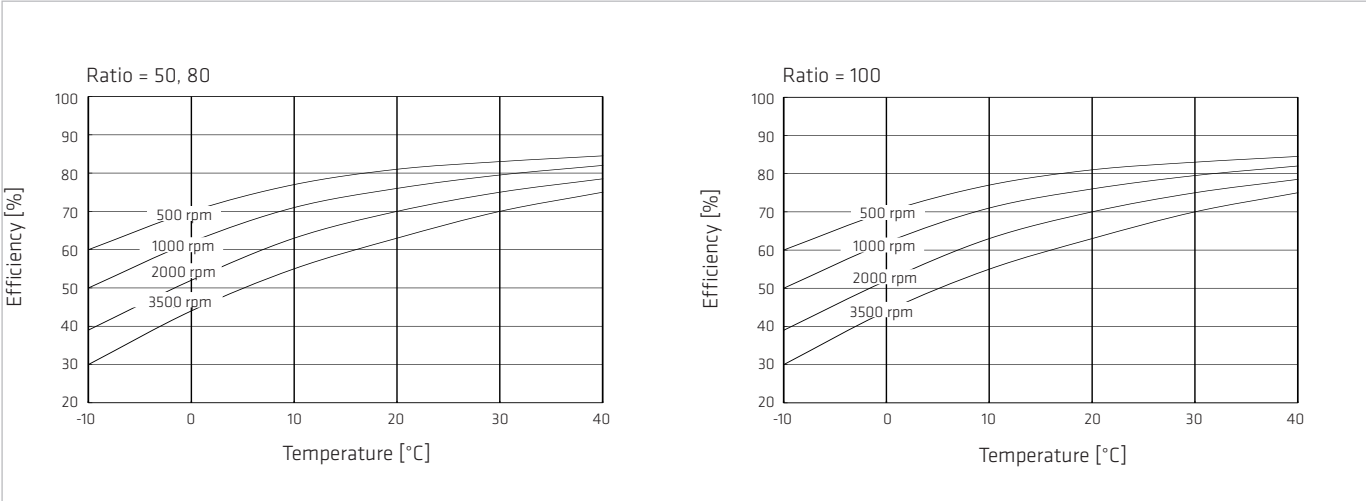| Calculation Procedure	Example
	Efficiency of HFUC-20-80-2A-GR with input speed n=1000 rpm output torque T=19.6 Nm at 20° C ambient temperature. Lubrication: Oil
The efficiency may be determined using the efficiency graphs.	From matching chart η = 78 %
Calculate the torque factor V. $$V = \frac{T_{av}}{T_N} \qquad \text{[Equation 25.2]}$$ With: T_{av} = Average torque T_N = Rated torque at rated speed	T_{av} = 19.6 Nm T_N = 34.0 Nm $$V = \frac{19.6 \text{ Nm}}{34.0 \text{ Nm}} = 0.57$$
K depending on gear type and V, see illustration 25.4	
Efficiency $\eta_L = \eta \cdot K$ [Equation 25.3]	η_L = 78 · 0.93 = 73 %

Calculating Factor K

Illustration 25.4

4.4.2 Efficiency Tables

Tables Grease

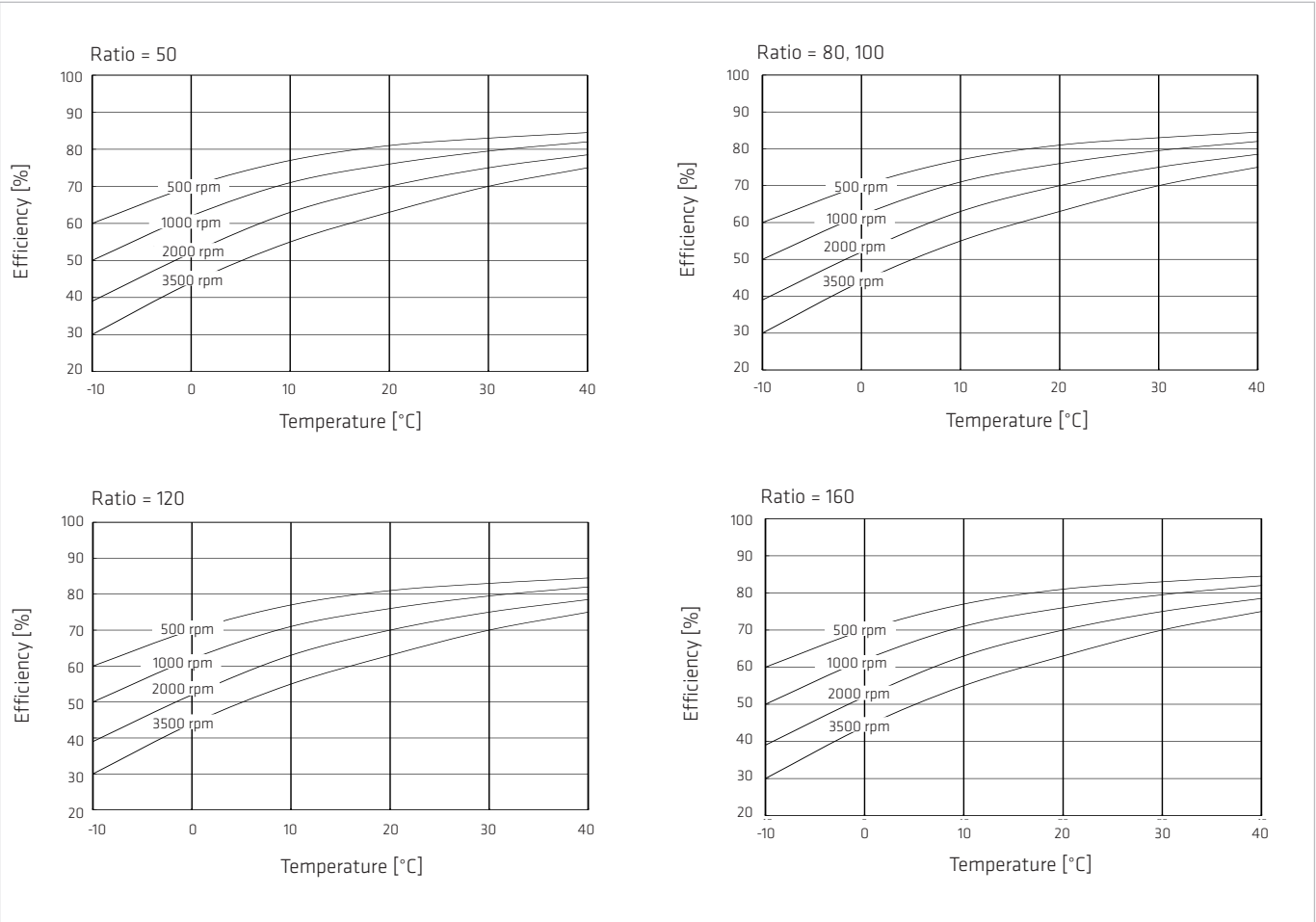Efficiency for grease lubrication at rated torque
Harmonic Drive® Grease.

Size 14

Illustration 26.1

Size 17 - 65

Illustration 26.1

4.5 No Load Starting-, Back Driving- and Running Torque

No Load Running Torque

The no load running torque is the torque required to maintain rotation of the input element (high speed side) at a defined input speed with no load applied to the output.

No Load Starting Torque

The no load starting torque is the quasistatic torque required to commence rotation of the input element (high speed side) with no load applied to the output element (low speed side).

No Load Back Driving Torque

The no load back driving torque is the torque required to commence rotation of the output element (low speed side) with no load applied to the input element (high speed side). The approximate range for no load back driving torque, based on tests of actual production gears, is shown in the matching table. In no case should the values given be regarded as a margin in a system that must hold an external load. Where back driving is not permissible a brake must be fitted.

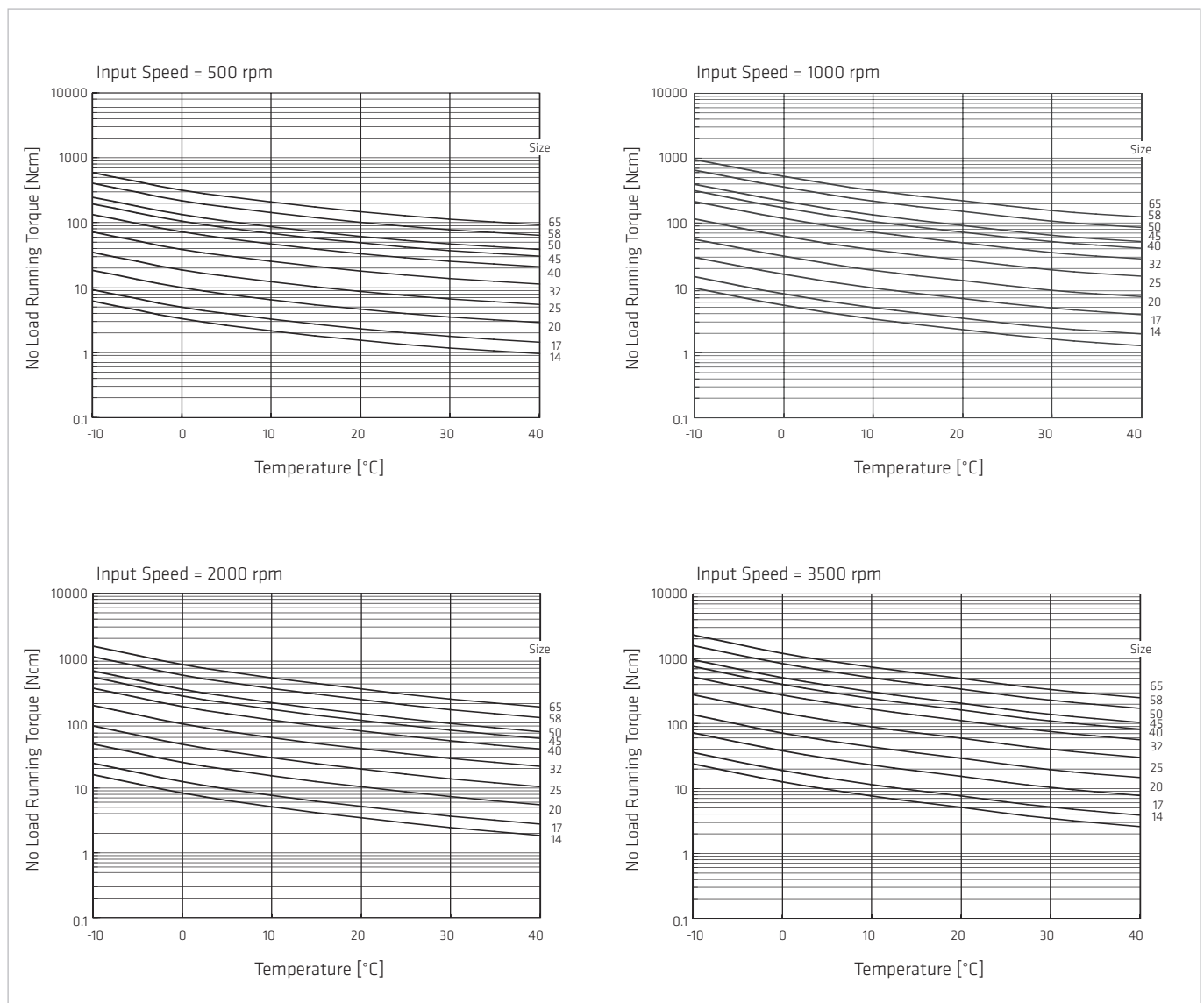The following curves are valid for: Harmonic Drive® grease, standard lubricant quantity
Gear ratio i = 100
For other ratios please apply the compensation values below.
For oil lubrication please contact Harmonic Drive AG.

4.5.1 No Load Running Torque

Illustration 27.1

Compensation Values for No Load Running Torque

When using gears with ratios other than i ≠ 100 please apply the compensation values from the table to the values taken from the curves.

Table 28.1   [Ncm]

Ratio	Size									
	14	17	20	25	32	40	45	50	58	65
50	0.5	0.9	1.4	2.5	5.2	9.2	12.7	17.0	25.8	–
80	0.1	0.1	0.2	0.4	0.8	1.4	2.0	2.6	4.0	5.4
120	–	-0.1	-0.2	-0.3	-0.6	-1.0	-1.4	-1.9	-2.9	-4.0
160	–	–	-0.4	-0.7	-1.4	-2.5	-3.5	-4.6	-7.0	-9.7

4.5.2 No Load Starting Torque

Table 28.2   [Ncm]

Ratio	Size									
	14	17	20	25	32	40	45	50	58	65
50	3.7	5.7	7.3	14	28	50	70	94	140	–
80	2.8	3.8	4.8	8.9	19	33	47	63	94	128
100	2.4	3.3	4.3	7.9	18	29	41	56	83	114
120	–	3.1	3.9	7.3	15	27	37	51	76	104
160	–	–	3.4	6.4	14	24	33	44	68	94

4.5.3 No Load Back Driving Torque

Table 28.3   [Nm]

Ratio	Size									
	14	17	20	25	32	40	45	50	58	65
50	2.2	3.4	4.4	8.2	17	30	42	56	84	–
80	2.7	3.7	4.6	8.6	18	32	45	60	90	123
100	2.8	4.0	5.2	9.5	21	35	49	67	100	137
120	–	4.5	5.6	10	21	40	54	73	110	151
160	–	–	6.6	12	26	45	64	85	130	180

4.6 Lubrication

Ratings and Lubricants

Harmonic Drive® products achieve the specified ratings and characteristics in the standard ambient temperature range (0° C to 40° C) when they are used with the lubricants named in the catalogue. Harmonic Drive AG can guarantee for the data specified in the catalogue only if a Harmonic Drive® grease or a mineral oil qualified for the specific product used. Lubricants and lubricant quantities other than recommended by Harmonic Drive AG should be qualified by means of prototype tests, as necessary.

The warranty becomes void when lubricants that have not been recommended in the Harmonic Drive® catalogue or that have not been approved in writing for the specific application are used.

4.6.1 Grease Lubrication

Application of Harmonic Drive® Lubricating Grease

Depending on product, size and if necessary ratio, the matching Harmonic Drive® grease should be selected. We recommend the application of the Harmonic Drive® lubricating greases according to the data in the tables 29.1 and 29.2.

Caution!

The Harmonic Drive® high performance greases 4BNo.2 and Flexolub-A1 have relatively low viscosities during operation. Therefore the design must be oil-tight. Because of the special characteristics of this grease, a small base oil leakage at the oil seals can not completely be ruled out.

Table 29.1

Grease	Ratio ≥ 50														
	Size														
	8	11	14	17	20	25	32	40	45	50	58	65	80	90	100
Flexolub A1	–			Standard for CPU and CobaltLine® Gears											
SK-1A	–				Standard										
SK-2	Standard				–										
4BNo.2	–			For heavy duty operation*											

Table 29.2

Grease	Ratio = 30						
	Size / Size						
	8	11	14	17	20	25	32
Flexolub A1	–			Standard for CPU			
SK-1A	–				Standard		
SK-2	Standard				–		
4BNo.2	–				For heavy duty operation*		

Notes:
* = recommended for heavy duty operation or at operating temperatures ranging from -10° C to +110° C
– = not approved

Table 30.1 gives some important information regarding Harmonic Drive® lubricating greases.

Table 30.1

| Type | Harmonic Drive® lubricating greases | | | |
| | Standard | | Special | |
	SK-1A	SK-2	Flexolub A1	4BNo.2
Operating temperature range	0° C ... +80° C	0° C ... +80° C	-40° C ... +120° C	-10° C ... +110° C
Base oil	Mineral oil	Mineral oil	PAO / Ester oil	Synthetic oil
Thickener	Lithium soap	Lithium soap	Lithium soap	Urea
Consistency class (NLGI)	2	2	1	1-2
Base oil viscosity (40° C; 100° C)	37; 5.9 mm²/St	37; 5.9 mm²/St	25; 5.2 mm²/St	50; 12 mm²/St
Drop point	197° C	198° C	180° C	247° C
Colour	yellow	green	magenta	pale yellow
Max. storage time in hermetically sealed container	5 years			
Ease of sealing (safety against grease- or base oil leakage at the oil seals)	+	+	+	+/-

Notes:
+   =   Good
+/- =   May be critical depending on design / mounting position / application, please contact Harmonic Drive AG

Safety data sheets or technical data sheets for the Harmonic Drive® lubricants are available from Harmonic Drive AG.

Special Operating Demands

Table 31.1 shows examples of lubricants for special operating demands. In individual cases other lubricants may be recommendable, and special limit values may have to be considered for product calculations at extended operating temperatures. Please ask Harmonic Drive AG for more information.

Table 31.1

Lubricants for special operating demands			
Application	Type	Manufacturer, Designation	Operating temperature range [1]
Broadband temperature range	Grease	Harmonic Drive®, Flexolub-A1	-40° C … +120° C [3]
Low temperature	Grease Oil	Harmonic Drive®, Flexolub-M0	-50° C … +120° C [2)5]
High temperature	Grease Oil	Mobil, Mobil Grease 28 Mobil, Mobil SHC 626	-55° C … +160° C [2] -15° C … +140° C [2]
Food-/pharmaceutical industry	Grease	Bechem, Berulub FG-H 2 SL	-40° C … +120° C [2)4]

Notes:
[1] Operating temperature = Lubricant temperature
[2] User specific prototype tests recommended
[3] Applicability confirmed for all Harmonic Drive® catalogue products with cup type Flexspline for size 14 and up. 1 kg bundles available at HDAG
[4] NSF-H1 certification. Applicability confirmed for HFUC-XX, CPU-XX, HFUS-XX, CPL-XX, CHA-XX with i=100 at full usage of the catalogue performance data. Please consult Harmonic Drive AG for i>100 applicable. For food/ pharmaceutical compatibility, grease change is necessary for output- and support bearings, if used. 400 g bundles available at Harmonic Drive AG.
[5] Recommended for applications requiring best possible efficiency at low temperatures. Not suitable for high output torque.

4.6.2 Oil Lubrication

Harmonic Drive® units with oil lubrication are customer specific solutions. Oil quantity and change interval are specified individually.

Table 31.2

Shared lubricating oils				
Manufacturer	Klüber	Mobil	Castrol	Shell
Designation	Syntheso D 68 EP	Mobilgear 600 XP 68	Optigear BM 68	Omala S2 G 68

Please note the information in section 5.5.4.

4.7 Axial Forces at the Wave Generator

When a Harmonic Drive® Gear is used as a speed reducer (torque input via Wave Generator), the deflection of the Flexspline leads to an axial force acting on the Wave Generator. This axial force acts in the direction of the Flexspline diaphragm. When the Harmonic Drive® Component Set is used as a speed accelerating gear (reverse operation, e. g. when braking), the axial force acts in the opposite direction. In any case the axial force must be absorbed by the input shaft (motor shaft). The Wave Generator thus needs to be fixed on the input shaft in the axial direction. In closed Harmonic Drive® Units and gearboxes the axial force is absorbed internally.

Illustration 32.1

Speed reducer — F_{AX} — F_{AX} — Reverse operation

Table 32.2

Ratio		
30	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 32°$	[Equation 32.3]
50	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 30° + 2\mu PF$	[Equation 32.4]
80...160	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 20° + 2\mu PF$	[Equation 32.5]

with:

F_{AX} = Axial force [N]
D = (Size) · 0.00254 [m]
T = Torque at the output [Nm]
μ = 0.07 Coefficient of friction
$2\mu PF$ = Additional force (only CSD) [N]

Example

Size 32 (CSD-32-50)
Output torque = 200 Nm
Coefficient of friction μ = 0.07

$$F_{AX} = 2 \cdot \frac{200 \text{ Nm}}{(32 \cdot 0.00254) \text{ m}} \cdot 0.07 \cdot \tan 30° + 16$$

F_{AX} = 215 N

Table 32.6

Sizes	14	17	20	25	32	40	50
$2\mu PF$ [N] for CSD and SHD	2.1	4.1	5.6	9.8	16	24	39

5. Installation and Operation

5.1 Transport and Storage

Gears should be transported in the original packaging. If the gear is not put into service immediately on receipt, it should be stored in a dry area in the original packaging. The permissible storage temperature range is -20° C to +60° C.

5.2 Gear Condition at Delivery

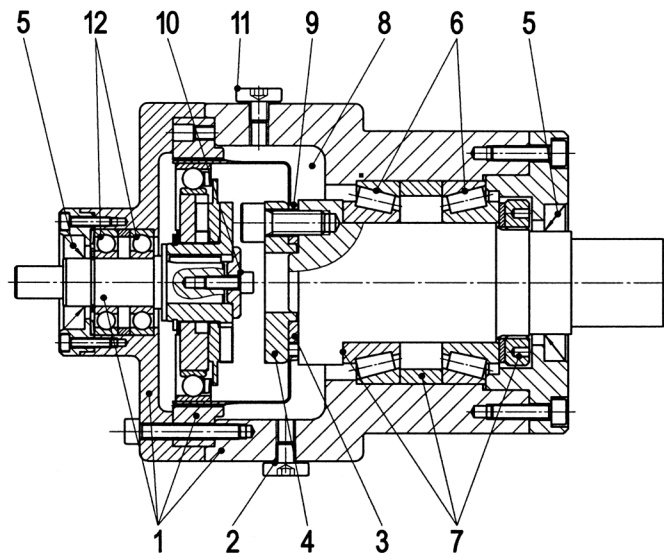The gears are generally delivered according to the dimensions indicated in the confirmation drawing.

The three basic components of the gear - the Flexspline, Wave Generator and Circular Spline - are matched and labelled 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 final numbers of the assembled gear components are identical.

5.3 Assembly Instructions

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 exploited.

Illustration 34.1

Careful attention should thus be paid to the following points:

1) Input shaft, Circular Spline and housing must be concentric.
2) Oil drain (for oil lubrication)
3) The Flexspline flange diameter must be concentric to Circular Spline.
4) A clamping ring with corner radius increases torque transmission capacity and prevents damage to Flexspline diaphragm.
5) A radial shaft seal for oil lubrication
6) Preloaded and backlashfree double bearing support for output shaft
7) Axial location of Flexspline
8) Air vent (depending on the application)
9) Flexspline and Circular Spline must be located in parallel and perpendicular to the output shaft.
10) Axial location of Wave Generator
11) Oil input (also enables assembly check)
12) Double bearing support for input shaft

Bearing Support for Input and Output Shafts

For 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. Even when only limited external loads are anticipated both input and output shafts must be fixed axially in order to avoid damage to the component set. Bearings must be selected whose radial play does not exceed ISO-standard C2 class or "normal" class. To fully exploit the accuracy of the gear we recommend a stiff output bearing design. The bearing should be axially and radially preloaded to eliminate backlash. Examples of correct bearing arrangements are shown in illustration 35.1.

Illustration 35.1

Screw Connections

The high torque capacity combined with the compact design of the Harmonic Drive® Gear demands a secure connection of both Flexspline and Circular Spline. To ensure that the screw connection is adequate please observe the following general guidelines:

- Base the calculation of torque transmitting capability on the VDI 2230 guideline.
- Use 12.9 quality screws.
- Do not use unsuitable locking devices such as spring washers or toothed discs.
- Ensure that the strength of the output shaft material is adequate.
- Ensure that the flange material is suitable for the pressure beneath the screw heads.
- Steel or cast iron is the preferred material for the female thread.
- Reduce the roughness of the mating surface to reduce the loss of preload by embedding.
- Ensure largest possible clamping length ratio (thickness of the clamped flanges versus diameter of the bolts).
- Clean, degrease and dry all mating surfaces to ensure adequate coefficient of friction. Loctite 574 can be applied to increase friction.
- Use approved screw tightening devices (torque wrench, torsional angle or yield controlled torque wrench if possible).
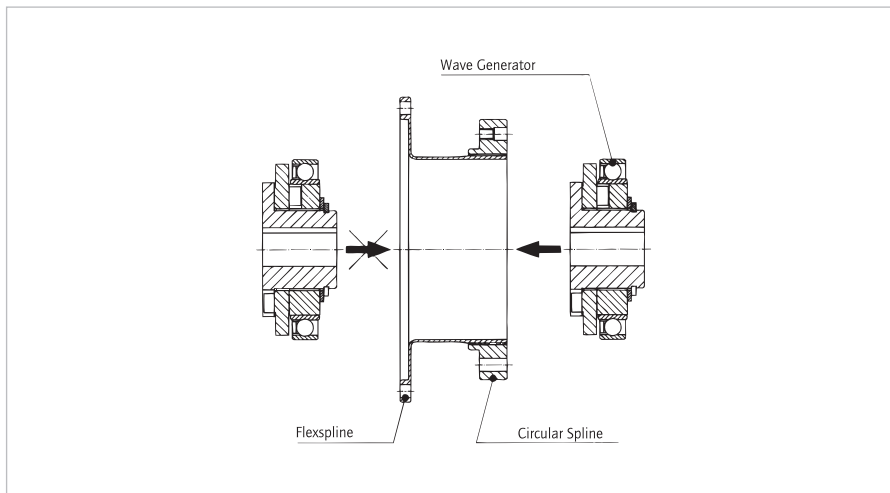- Apply Loctite No. 243 to the threads of bolts.

Assembly

During assembly the following general points should be considered:

The gear components have to be centred accurately within and relative to the housing.

First of all, the Flexspline and Circular Spline must be fixed. To ensure a centred position of the Circular Spline, the fastening screws should be tightened crosswise using successively increased torque. Only then should the Wave Generator be inserted into the Flexspline, as shown in illustration 48.2.

Caution: The assembly of the Wave Generator must be executed in the direction of the arrow. During the insertion of the Wave Generator into the Flexspline the Flexspline adopts the elliptical shape of the Wave Generator.

Illustration 36.1

The assembly of the Wave Generator must be executed in the direction of the arrow.

5.4 Recommended Tolerances for Assembly

In order for the new features of Harmonic Drive® Units to be exploited fully, it is essential that the tolerances according to table 37.1 are observed for the input assembly.
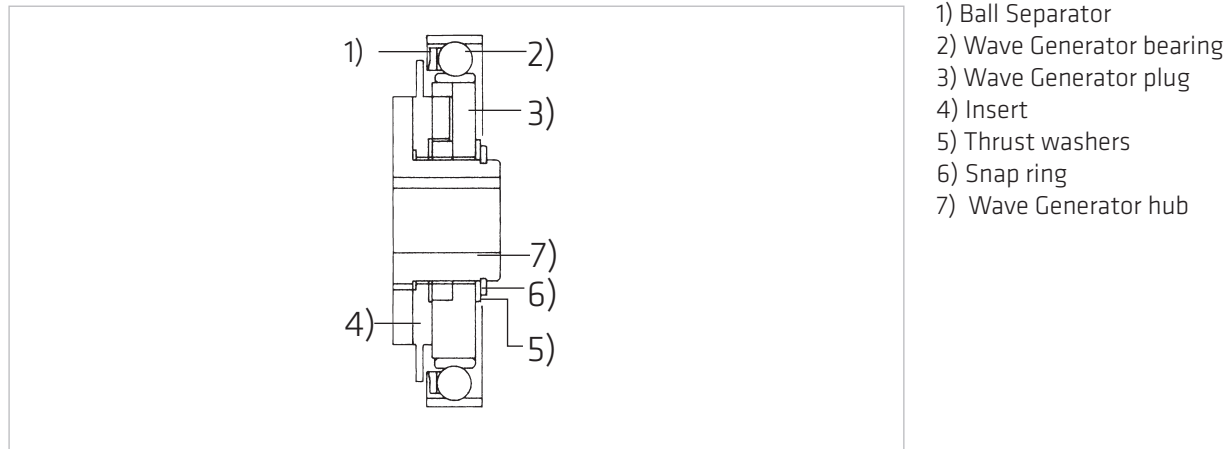
Illustration 37.1

① Recommended shaft tolerances h6 or H6   ② Recommended shaft tolerances h6   ③ Recommended housing tolerances H7

Table 37.2   [mm]

Size	14	17	20	25	32	40	45	50	58	65
a	0.011	0.012	0.013	0.014	0.016	0.016	0.017	0.018	0.020	0.023
b	0.016	0.021	0.024	0.035	0.042	0.048	0.053	0.057	0.062	0.035
c	0.015	0.018	0.019	0.022	0.022	0.024	0.027	0.030	0.032	0.035
d	0.011	0.015	0.017	0.024	0.026	0.026	0.027	0.028	0.031	0.034
e	0.011	0.015	0.017	0.024	0.026	0.026	0.027	0.028	0.031	0.034
f	0.017 (0.008)	0.020 (0.010)	0.024 (0.012)	0.024 (0.012)	0.024 (0.012)	0.032 (0.012)	0.032 (0.013)	0.032 (0.015)	0.032 (0.015)	0.032 (0.015)
g	0.030 (0.016)	0.034 (0.018)	0.044 (0.019)	0.047 (0.022)	0.050 (0.022)	0.063 (0.024)	0.065 (0.027)	0.066 (0.030)	0.068 (0.033)	0.070 (0.035)

The values in brackets are the recommended tolerances for component sets featuring a Wave Generator without Oldham coupling. The Oldham coupling serves to compensate for eccentricity of the input shaft and is available in the standard version. For the direct mounting of a Wave Generator without Oldham coupling (optional) on a motor shaft, the shaft tolerances should fulfill the DIN 42955 R standard.

5.5 Wave Generator Components

Illustration 38.1 shows a standard Wave Generator with Oldham Coupling.

Illustration 38.1

1) Ball Separator
2) Wave Generator bearing
3) Wave Generator plug
4) Insert
5) Thrust washers
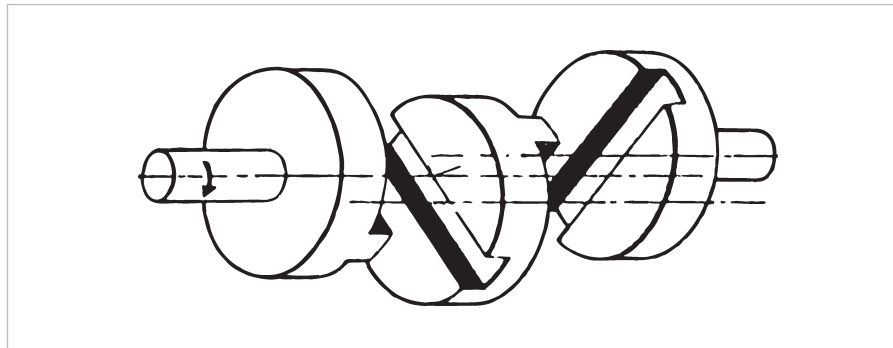6) Snap ring
7) Wave Generator hub

Wave Generator Modifications

HFUS component sets have to compensate for runout of the motor shaft by default an Oldham coupling, see illustration 38.2.

Principle of an Oldham Coupling

Illustration 38.2

5.6 Bore Diameter for Solid Wave Generators

If a large-bore Wave Generator or an input coupling completely free of backlash is required, the Oldham coupling may be removed and the input shaft can be attached directly to the Wave Generator plug. This is the so called "Solid Wave Generator" configuration. The Wave Generator bore may be enlarged or splined to accept a hollow shaft or a splined shaft. The maximum allowable bore diameter, with or without keyway or splines, is given in table 39.2. Use of a Solid Wave Generator demands tighter tolerances for the motor shaft and housing, as described in the section "Design Guidelines/ Assembly Tolerances" for the selected product.

Maximum Bore Diameter Without Oldham Coupling

Illustration 39.1

Table 39.2 [mm]

Size	14	17	20	25	32	40	45	50	58	65
L_W for key to DIN 6885 T1	12	13	17	22	28	34	39	44	50	56
L	17	20	23	28	36	42	47	52	60	67

5.7 Lubrication

At the time of delivery, the gears are conserved with preservation 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.

5.7.1 Grease Lubrication

Amount of Grease

Table 39.3 includes the recommendations by Harmonic Drive® for standard applications amounts of grease. Special applications may possibly require special lubricants and amounts of grease. If in doubt please contact the Harmonic Drive AG.

Table 39.3

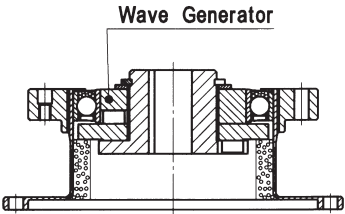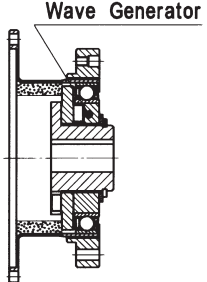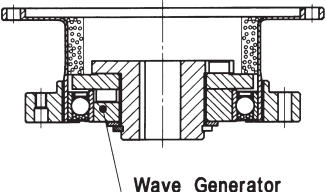| Size		14	17	20	25	32	40	45	50	58	65
Standard grease quantity	ca. [g]	5.5	10	16	40	60	130	180	260	360	440
	ca. [cm³]	6	11	18	44	66	143	198	286	396	484
Additionally required grease quantity for operation with Wave Generator above	ca. [g]	2	3	4	6	14	27	54	90	108	141
	ca. [cm³]	2	3	4	7	16	30	60	100	120	155
Dimensions (see illustration 40.1)	ca. [mm]	3	4	4.5	5.5	7	9.5	11	12	13.5	15

Grease Lubrication

Illustration 40.1 shows the areas to be lubricated, see also table 39.3. During operation, the 4BNo.2 grease becomes relatively liquid. Therefore the gear must be sealed as for oil lubrication, when this grease is used. If required, please ask Harmonic Drive® for further information.

Illustration 40.1

The required amount of grease is dependent on the size and the operating position of the gear.
The operating positions "Wave Generator above" or "Wave Generator below" refer to the relative position of the Wave Generator to Flexspline flange, see illustration 40.2

Illustration 40.2

Operating Positions		
Wave Generator below	Wave Generator vertical	Wave Generator above

Operation mainly with Wave Generator in vertical position or below
The supplied grease quantity is calculated for a Unit operating mainly with Wave Generator in vertical position or below. See table 39.3.

Operation mainly with Wave Generator above
If the gear is mainly operated with Wave Generator above additional grease must be supplied above the Wave Generator, see illustration 40.3 and table 39.3.

Illustration 40.3

If the units are used mainly with Wave Generator above, then additional grease lubrication is necessary.

5.7.2 Grease Reservoir

For assembly please ensure that the grease reservoir is filled up with grease (dimension c and ø d in table 41.1 and illustration 41.2).
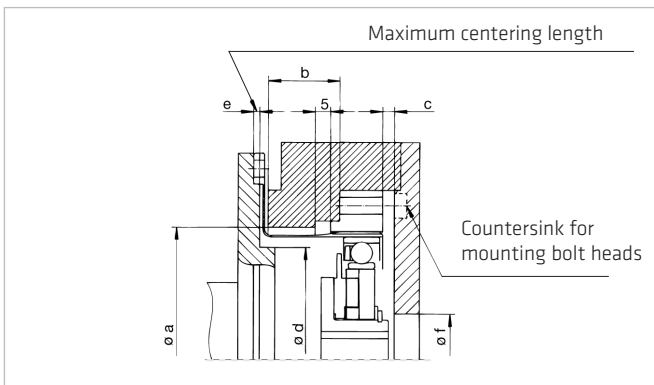
Table 41.1

Size	14	17	20	25	32	40	45	50	58	65
ø a	38	45	53	66	86	106	119	133	154	172
b	14.6	16.4	17.8	19.8	23.2	28.6	31.9	34.2	40.1	43
c*	1	1	1.5	1.5	1.5	2	2	2	2.5	2.5
c**	3	3	4.5	4.5	4.5	6	6	6	7.5	7.5
ø d	31	38	45	56	73	90	101	113	131	150
e	1.7	2.1	2	2	2	2	2.3	2.5	2.9	3.5
ø f	16	26	30	37	37	45	45	45	56	62

*   Horizontal and Vertical - Wave Generator below
** Vertical - Wave Generator above

Illustration 41.2

5.7.3 Grease Change

To change the grease the component set should be completely disassembled and cleaned before regreasing. Fresh grease should be applied generously to the inside of the Flexspline, the Wave Generator bearing, the Oldham coupling and the teeth of the Circular Spline and Flexspline.

In illustration 41.3, the grease change interval depending on the grease temperature is given. The number of allowable revolutions of the input shaft which represents the grease change interval can be estimated as shown in the example. This means, that for a temperature of SK-1A or SK-2 grease of 40° C a change should take place after approx. 8.5×10^8 revolutions of the input shaft. All grease change data refers to rated speed and rated torque.

Illustration 41.3

Equation 41.4

$$L_{GT} = L_{GTn} \cdot \left(\frac{T_N}{T_{av}} \right)^3$$

L_{GT} = Number of Wave Generator revolutions until grease change

L_{GTn} = see diagram

T_N = Rated torque

T_{av} = Average torque

5.7.4 Gears with Oil Lubrication

Harmonic Drive® Units with oil lubrication are generally customer-specific solutions. Please follow the notes given on the confirmation drawing and refer to table 31.2 for allowed oil types. The oil temperature during operation must not exceed 90° C. Oil must be filled into the unit by the customer as the standard delivery does not include any oil lubricant.

Oil Quantity

The values specified in the confirmation drawing include the valid oil quantities to fill in. The oil quantity defined on the confirmation drawing must be obeyed in any case. Too much oil results in excessive heat production and early wear due to the thermal destruction of the oil. If the oil level is too low, this may lead to early wear as a result of lubricant deficiency. See illustration 42.1 and table 42.3.
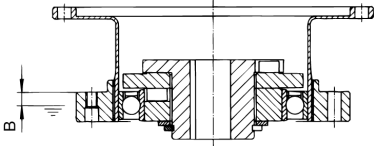
Illustration 42.1

Operating Positions		
Wave Generator above	Wave Generator perpendicular	Wave Generator below
B = Oil level	A = Oil level	B = Oil level

Table 42.2

Minimum amount of oil										
Size	14	17	20	25	32	40	45	50	58	65
Liter	0.01	0.02	0.03	0.07	0.13	0.25	0.32	0.4	0.7	1,0

Table 42.3   [mm]

Oil levels										
Size	14	17	20	25	32	40	45	50	58	65
A	10	12	14	17	24	31	35	38	44	50
B	2.5	3	3	5	7	9	10	12	13	15

The required oil quantity is dependent on the design. Therefore, the quantity specified in the drawing/service manual of the machine is decisive for the oil quantity to fill in. Please also consider illustration 45.1 and table 45.3. The defined oil levels must be obeyed in any case. Too much oil results in excessive heat production and early wear due to thermal destruction of the oil. If the oil level is too low, this may lead to early wear as a result of lubricant defiency.

When the gear is to be used with the Wave Generator above or below, special consideration must be given because even small changes of the oil level affect the churning losses.
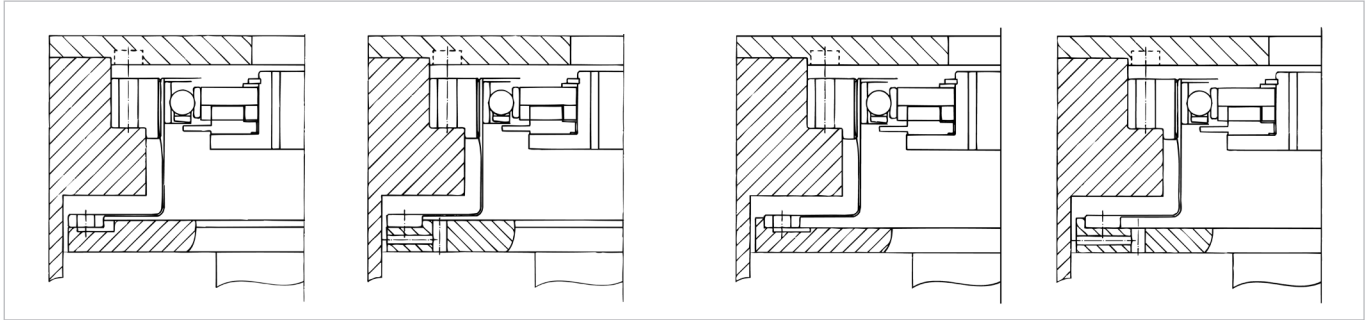
Oil Change

The first oil change is necessary after 100 hours of operation. Subsequent oil change intervals depend on the operating conditions, but should take place at intervals of approximately 1000 running hours. To change the oil, the used oil must be drained completely and fresh oil must be filled in.

5.7.5 Lubrication Holes

Example of pressure compensation design for vertical installation with Wave Generator up.

Illustration 43.1

5.8 Preparation for Assembly

Assembly Preparation
The gear assembly must be carried out very carefully and within a clean environment. Please make sure that during the assembly procedure no foreign particles enter the gear.

General information
Clean, degrease and dry all mating surfaces to ensure an adequate coefficient of friction. The values given here are valid for 12.9 quality screws which must be tightened by means of a torque wrench. Locking devices such as spring washers or toothed washers should not be used.

Auxiliary materials for assembly
For the assembly, we recommend the application of the following auxiliary materials or the use of those with similar characteristics. Please pay attention to the application guidelines given by the manufacturer. Auxiliary materials must not enter the gear.

Surface sealing
• Loctite 5203
• Loxeal 28-10
Recommended for all mating surfaces, if the use of o-ring seals is not intended.

Screw fixing
• Loctite 243
This adhesive ensures that the screw is fixed and also provides a good sealing effect. Loctite 243 is recommended for all screw connections.

Assembly paste
• Klüber Q NB 50
Recommended for o-rings which may come out of the groove during the assembly procedure. Before starting with the assembly you should spread some grease (which you can take from the gear) on all other o-rings.

Adhesives
• Loctite 638
Apply Loctite 638 to the connections between motor shaft and Wave Generator. You should make use of it only if this is specified in the confirmation drawing.

5.9 Assembly

The assembly must take place basically without impact. The assembly instructions of the machine manufacturer are to be considered. All screws must be tightened crosswise in 3 steps to the prescribed torque.

Assembly procedure
The assembling method of the gear depends strongly on the design details. Thus, this assembly manual only comprises standard information.

Basically first the Circular Spline (CS) and Flexspline (FS) should to be mounted and screwed down. The assembly of these two components can take place in any order.

The Wave Generator (WG) should be shifted at last into the pre-mounted components Flexspline/Circular Spline. If the assembling sequence described above cannot be observed please ask Harmonic Drive® whether in the concrete case another sequence is admissible.

Note:
Before the Wave Generator is set in position, the Circular Spline fixing screws must be tightened. Otherwise the Circular Spline would deform under the pre-load initiated by the Wave Generator. This could cause the gear to run roughly.
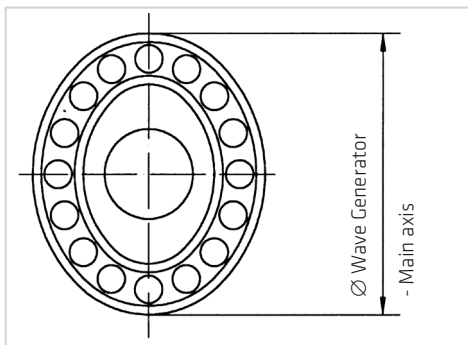
For the planning of the assembly sequence it may be helpful to know the max. diameter of the Wave Generator.
See illustration 44.2. In table 44.1 the diameters of the Wave Generator main axes are indicated.

Table 44.1 [mm]

Size	14	17	20	25	32	40	45	50	58	65
ca. Ø Wave Generator - Main axis	36	43	50	63	82	100	114	125	146	164

Illustration 44.2

5.9.1 Assembly of the Circular Spline

The Circular Spline must not be bended during the assembly. Therefore it is particularly important that the mounting base of the Circular Splineis absolutely even and that the mounting base centering causes neither clamping strength nor radial clearance.

Explanation:
A slightly deformed Circular Spline can result in irregular running characteristics. If a deformation of the Circular Spline is suspected it should be verified whether the Circular Spline can rotate freely within its locating bore in the machine housing without any friction. Even slight friction may be an indicator for a possible radial deformation of the Circular Spline. In this case the tolerances of the machine housing and the Circular Spline must be checked.

For grease lubrication the Circular Spline teeth must be lubricated in accordance with illustration 40.1.

Circular Spline Screws

Table 45.1

Size		14	17	20	25	32	40	45	50	58	65
Number of screws		8	16	16	16	16	16	16	16	16	16
Size of screws		M3	M3	M3	M4	M5	M6	M8	M8	M10	M10
Pitch circle diameter	[mm]	44	54	62	75	100	120	140	150	175	195
Clamping torque	[Nm]	2.0	2.0	2.0	4.5	9.0	15.3	37	37	74	74
Torque transmitting capacity	[Nm]	72	175	196	419	901	1530	3238	3469	6475	7215

The tables are valid for completely degreased pads (friction coefficient μ_k = 0.15) and metric socket head cap screws according to EN ISO 4762 in 12.9 quality, untreated, oiled, with μ_{total} = 0.12.

5.9.2 Assembly of the Flexspline

Care must be taken that the heads of clamping bolts, washers, nuts or clamping rings do not interfere with local flexing of the Flexspline. Otherwise eventual failure will result.

For this reason, fastening elements must not enter the region which is marked by ø D. Please refer to illustration 45.2.

Illustration 45.2

Right

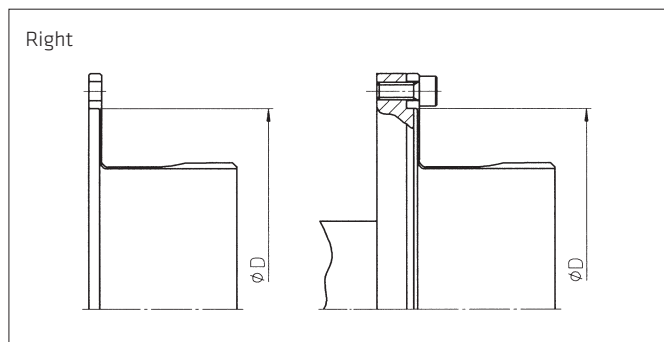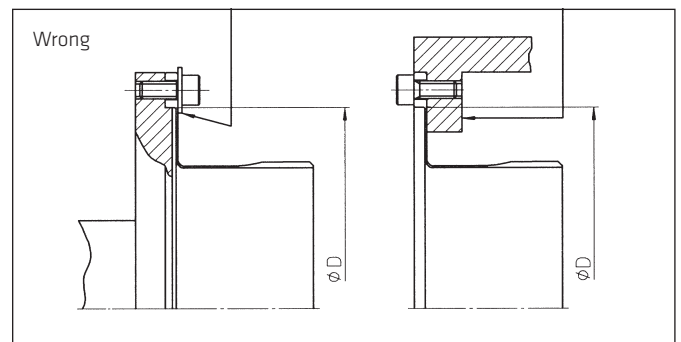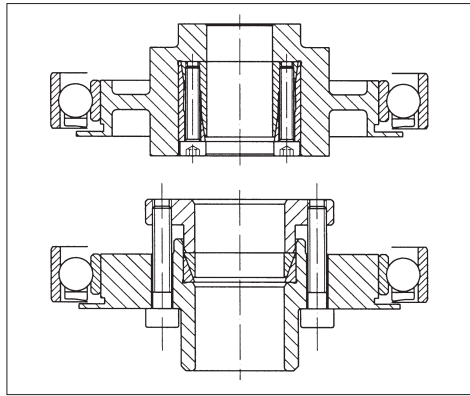Illustration 45.3

Wrong

Table 45.4 [mm]

Size	14	17	20	25	32	40	45	50	58	65
ø D	48	60	70	88	114	140	158	175	203	232

5.9.3 Flexspline Screws

The connection of the Flexspline to the output is normally realised with screws or in case of higher torques with screws and pins. If the load is below the limit for repeated peak torque the connection is carried out with screws as shown in table 46.1.

Flexspline Screws

Table 46.1

Size		14	17	20	25	32	40	45	50	58	65
Number of screws		8	12	12	12	12	12	18	12	16	16
Size of screws		M3	M3	M3	M4	M5	M6	M6	M8	M8	M10
Pitch circle diameter	[mm]	54	66	76	96	124	152	180	200	226	258
Screw tightening torque	[Nm]	2.4	2.4	2.4	5.4	10.8	18.5	18.5	44	44	74
Transmittable torque	[Nm]	88	198	228	486	1000	1740	3098	4163	5076	6272

The tables are valid for completely degreased pads (friction coefficient μ_k = 0.15) and metric socket head cap screws according to EN ISO 4762 in 12.9 quality, untreated, oiled, with μ_{total} = 0.12.

5.9.4 Assembly of the Wave Generator to the Input Shaft

Before or after the assembly to the input shaft the Wave Generator is to be lubricated according to section 5.7. During the assembly the axial mounting position indicated on the catalogue/confirmation drawing is to be considered.

When a clamping element is used please thighten the clamping element screws crosswise and in five steps up to the torque indicated on the drawing (alternatively: manufacturer information), see also illustration 47.1. When the Wave Generator hub is glued to the input shaft please consider section 5.8..

Illustration 47.1

Design examples for Solid Wave Generator
with clamping element

5.9.5 Check before Assembly of the Wave Generator

Final check of position of the Wave Generator. For some clamping elements an axial movement may occur during tightening. Please take account of this effect when positioning the Wave Generator on the shaft.

Check whether the Wave Generator is lubricated in accordance with section 5.7. When the gear is oil lubricated, fill in the prescribed oil quantity.

5.9.6 Final Check of Position of the Wave Generator

When the Wave Generator is assembled into the Flexspline please consider that the parts must not be tilted during assembly. By parallel assembly it is ensured that the teeth of Flexspline and Circular Spline mesh symmetrically.

Alternatively the assembly can be executed during slowly rotation of the input shaft (n < 10 rpm). This method eases the assembly.

Illustration 47.2

The assembly of the Wave Generator must be executed in the direction of the arrow.
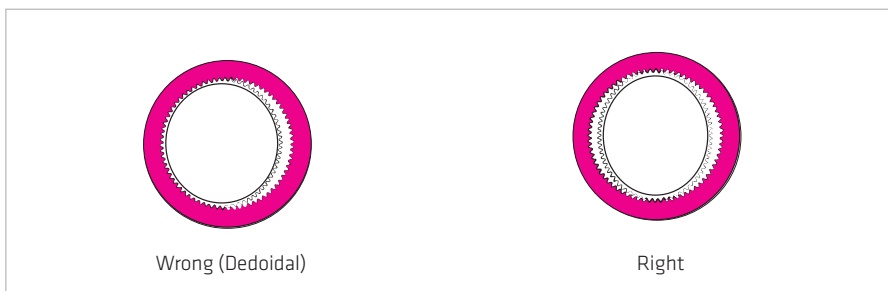
5.9.7 Assembly Control

Very rarely, an eccentric tooth mesh, called dedoidal, may occur (see illustration 48.1). The correct assembly can be checked as follows:

• Check the running behaviour by rotating the input shaft (in case of types with input shaft). Alternatively you may rotate the output flange. If you notice torque variations these may be caused by eccentric tooth mesh.

• Check the running behaviour and the motor current while the motor is rotating. Strong fluctuations in the motor current and/or an excessive no-load current may be the result of an eccentric tooth mesh.

In case of a dedoidal assembly you can avoid permanent damage to the gear if the wrong installation is recognized by means of the above mentioned inspection. The problem can be solved by disassembling the gear followed by a new assembly.

Illustration 48.1

Wrong (Dedoidal) Right

Correct assembly of component sets may be checked in one of four ways:

Illustration 48.2

• By visual observation, if the tooth mesh is exposed.
• In case the gearing is not visible, the input shaft can be rotated by hand. Uneven rotation suggests dedoidal tooth mesh.
• If the Wave Generator is connected to a motor, an unusually high motor current indicates dedoidal tooth mesh.
• A dial gauge can be inserted through an access hole near the Circular Spline to touch the surface of the Flexspline. A quasi sinusoidal deflection during one revolution of the Flexspline indicates correct assembly as shown in illustration 48.2.

6. Decommissioning and Disposal

The gears, servo actuators and motors from Harmonic Drive AG contain lubricants for bearings and gears as well as electronic components and printed circuit boards. Since lubricants (greases and oils) are considered hazardous substances in accordance with health and safety regulations, it is necessary to dispose of the products correctly. Please ask for safety data sheet where necessary.

7. Glossary

7.1 Technical Data

AC Voltage constant k_{EM} [V_{rms} / 1000 rpm]

Effective value of the induced motor voltage measured at the motor terminals at a speed of 1000 rpm and an operating temperature of 20° C.

Ambient operating temperature [° C]

The intended operating temperature for the operation of the drive.

Average input speed (grease lubrication) $n_{av\,(max)}$ [rpm]

Maximum permissible average gear input speed for grease lubrication.

Average input speed (oil lubrication) $n_{av\,(max)}$ [rpm]

Maximum permissible average gear input speed for oil lubrication.

Average torque T_A [Nm]

When a variable load is applied to the gear, an average torque should be calculated for the complete operating cycle. This value should not exceed the specified T_A limit.

Backlash (Harmonic Planetary gears) [arcmin]

When subjected to the rated torque, Harmonic Planetary gears display characteristics shown in the hysteresis curve. When a torque is applied to the output shaft of the gear with the input shaft locked, the torque-torsion relationship can be measured at the output. Starting from point 0 the graph follows successive points A-B-A'-B'-A where the value B-B' is defined as the backlash or hysteresis.

Brake closing time t_c [ms]

Delay time to close the brake.

Brake current to hold I_{HBr} [A_{DC}]

Current for applying the brake.

Brake current to open I_{OBr} [A_{DC}]

Current required to open the brake.
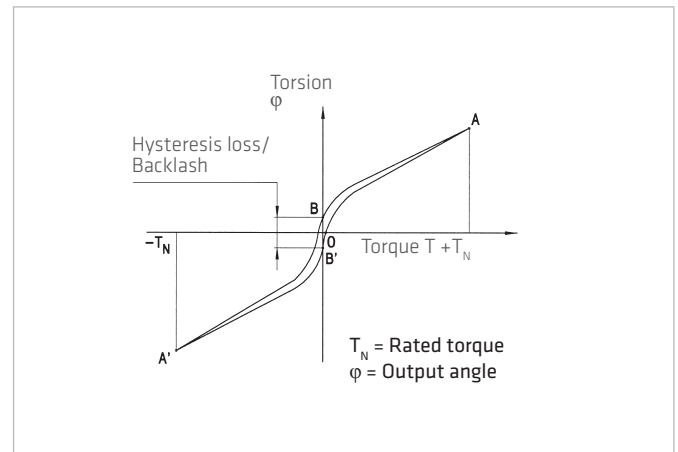
Brake holding torque T_{BR} [Nm]

Torque the actuator can withstand when the brake is applied, with respect to the output.

Brake opening time t_0 [ms]

Delay time for opening the brake.

Brake voltage U_{Br} [VDC]

Terminal voltage of the holding brake.

Continuous stall current I_0 [A_{rms}]

Effective value of the motor phase current to produce the stall torque.

Continuous stall torque T_0 [Nm]

Allowable actuator stall torque.

Demagnetisation current I_E [A_{rms}]

Current at which rotor magnets start to demagnetise.

Dynamic axial load $F_{A\,dyn\,(max)}$ [N]

With the bearing rotating, this is the maximum allowable axial load with no additional radial forces or tilting moments applied.

Dynamic load rating C [N]

Maximum dynamic load that can be absorbed by the output bearing before permanent damage may occur.

Dynamic radial load $F_{R\,dyn\,(max)}$ [N]

With the bearing rotating, this is the maximum allowable radial load with no additional axial forces or tilting moments applied.

Dynamic tilting moment $M_{dyn\,(max)}$ [Nm]

With the bearing rotating, this is the maximum allowable tilting moment with no additional axial forces or radial forces applied.

Electrical time constant τ_e [s]

The electrical time constant is the time required for the current to reach 63% of its final value.

Hollow shaft diameter d_H [mm]

Free inner diameter of the continuous axial hollow shaft.

Inductance (L-L) L_{L-L} [mH]

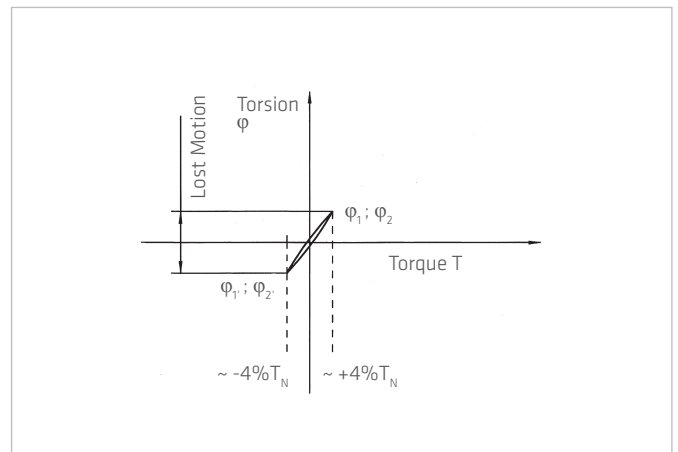Terminal inductance calculated without taking into account the magnetic saturation of the active motor parts.

Lost Motion (Harmonic Drive® Gearing) [arcmin]

Harmonic Drive® Gearing exhibits zero backlash in the teeth. Lost motion is the term used to characterise the torsional stiffness in the low torque region.

The illustration shows the angle of rotation φ measured against the applied output torque as a hysteresis curve with the Wave Generator locked. The lost motion measurement of the gear is taken with an output torque of about ± 4% of the rated torque.

Maximum current I_{max} [A]

The maximum current is the maximum current that can be applied for a short period.

Maximum DC bus voltage $U_{DC\,(max)}$ [VDC]

The maximum DC bus power supply for the correct operation of the actuator. This value may only be exceeded for a short period during the braking or deceleration phase.

Maximum hollow shaft diameter $d_{H\,(max)}$ [mm]

For gears with a hollow shaft, this value is the maximum possible diameter of the axial hollow shaft.

Maximum input speed (grease lubrication) $n_{in\,(max)}$ [rpm]

Maximum allowable input speed with grease lubrication.

Maximum input speed (oil lubrication) $n_{in\,(max)}$ [rpm]

Maximum allowable input speed for gearing with oil lubrication.

Maximum motor speed n_{max} [rpm]

The maximum allowable motor speed.

Maximum output speed n_{max} [rpm]

The maximum output speed. Due to heating issues, this may only be momentarily applied during the operating cycle. The maximum output speed can occur any number of times as long as the calculated average speed is within the permissible continuous operation duty cycle.

Maximum output torque T_{max} [Nm]

Specifies the maximum allowable acceleration and deceleration torques. For highly dynamic processes, this is the maximum torque available for a short period. The maximum torque can be parameterised by the control unit where the maximum current can be limited. The maximum torque can be applied as often as desired, as long as the calculated average torque is within the permissible continuous operation duty cycle.

Maximum power P_{max} [W]

Maximum power output.

Mechanical time constant τ_m [s]

The mechanical time constant is the time required to reach 63% of its maximum rated speed in a no-load condition.

Momentary peak torque T_M [Nm]

In the event of an emergency stop or collision, the Harmonic Drive® Gearing may be subjected to a brief collision torque. The magnitude and frequency of this collision torque should be kept to a minimum and under no circumstances should the collision torque occur during the normal operating cycle.

Moment of inertia J [kgm²]

Mass moment of inertia at motor side.

Moment of inertia J_{in} [kgm²]

Mass moment of inertia of the gearing with respect to the input.

Moment of inertia J_{out} [kgm²]

Mass moment of inertia with respect to the output.

Motor terminal voltage (Fundamental wave only) U_M [V_{rms}]

Required fundamental wave voltage to achieve the specified performance. Additional power losses can lead to restriction of the maximum achievable speed.

Number of pole pairs p

Number of magnetic pole pairs on the rotor of the motor.

Offset R [mm]

Distance between output bearing and contact point of the load.

Pitch circle diameter d_p [mm]

Pitch circle diameter of the output bearing rolling elements.

Protection IP

The degree of protection according to EN 60034-5 provides suitability for various environmental conditions.

Rated current I_N [A]

RMS value of the sinusoidal current when driven at rated torque and rated speed.

Rated motor speed n_N [rpm]

The motor speed which can be continuously maintained when driven at rated torque T_N, when mounted on a suitably dimensioned heat sink.

Rated power P_N [W]

Output power at rated speed and rated torque.

Rated speed n_N [rpm], Mechanical

The rated speed is a reference speed for the calculation of the gear life. When loaded with the rated torque and running at rated speed the gear will reach the expected operating life L_{50}. The speed n_N is not used for dimensioning the gear.

[rpm]

Product series	n_N
CobaltLine®, HFUC, HFUS, CSF, CSG, CSD, SHG, SHD	2000
PMG size 5	4500
PMG size 8 to 14	3500
HPG, HPGP, HPN	3000

Rated torque T_N [Nm], Servo

The output torque which can be continuously transmitted when driven at rated input speed, when mounted on a suitably dimensioned heat sink.

Rated torque T_N [Nm], Mechanical

The rated torque is a reference torque for the calculation of the gear life. When loaded with the rated torque and running at rated speed the gear will reach the average life L_{50}. The rated torque T_N is not used for the dimensioning of the gear.

Rated voltage U_N [V_{rms}]

Supply voltage for operation with rated torque and rated speed.

Ratio i [ ]

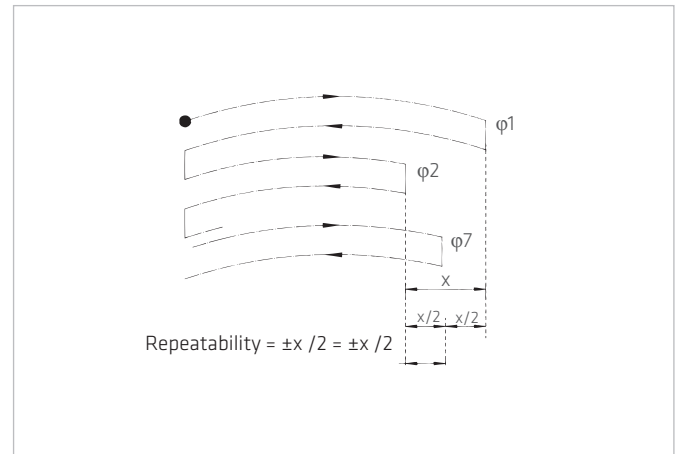The ratio is the reduction of input speed to the output speed.

Note for Harmonic Drive® Gears: The standard version has the Wave Generator as the input element, the Flexspline as the output element and the Circular Spline is fixed to the housing. Since the direction of rotation of the input (Wave Generator) is opposite to the output (Flexspline), a negative ratio should be used for calculations in which the direction of rotation is to be considered.

Repeatability [arcmin]

The repeatability of the gear describes the position difference measured during repeated movement to the same desired position from the same direction. The repeatability is defined as half the value of the maximum difference measured, preceded by a ± sign.

Repeatable peak torque T_R [Nm]

Specifies the maximum allowable acceleration and braking torques. During the normal operating cycle the repeatable peak torque T_R should be not be exceeded.

Resistance (L-L, 20° C) R_{L-L} [Ω]

Winding resistance measured between two conductors at a winding temperature of 20° C.

Size

1) Actuators / Gears with Harmonic Drive® gears or Harmonic Planetary gears
The frame size is derived from the pitch circle diameter of the gear teeth in inches multiplied by 10.

2) CHM Servo motor series
The size of the CHM servo motors is derived from the stall torque in Ncm.

3) Direct drives from the TorkDrive® series
The size of the TorkDrive® series is the outer diameter of the iron core of the stator.

Static load rating C_0 [N]

Maximum static load that can be absorbed by the output bearing before permanent damage may occur.

Static tilting moment M_0 [Nm]

With the bearing stationary, this is the maximum allowable radial load with no additional axial forces or tilting moments applied.

Tilting moment stiffness K_B [Nm/arcmin]

Describes the relationship between the tilting angle of the output bearing and an applied moment load.

Torque constant (motor) k_{TM} [Nm/A_{rms}]

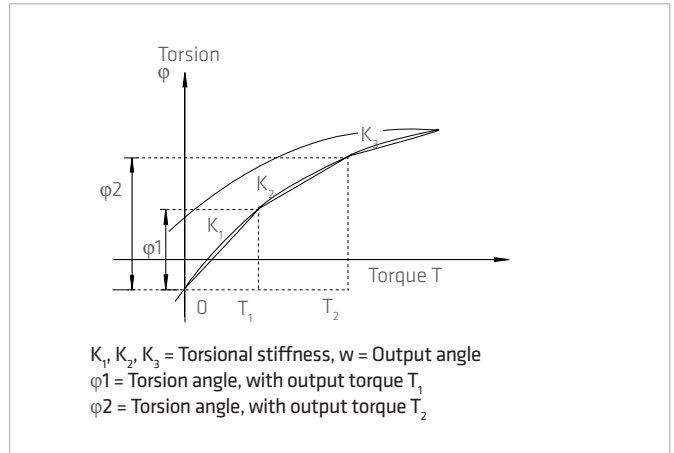Quotient of stall torque and stall current.

Torque constant (output) k_{Tout} [Nm/A$_{rms}$]

Quotient of stall torque and stall current, taking into account the transmission losses.

Torsional stiffness
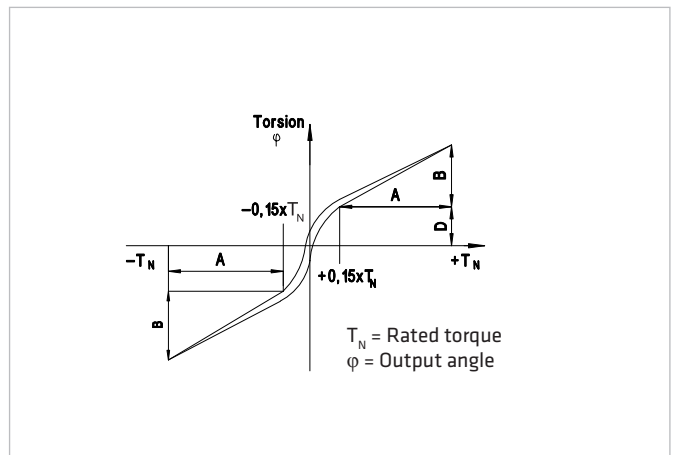## (Harmonic Drive® Gears) K_3 [Nm/rad]

The amount of elastic rotation at the output for a given torque with the Wave Generator blocked. The torsional stiffness K_3 describes the stiffness above a defined reference torque where the stiffness is almost linear.

The value given for the torsional stiffness K_3 is an average that has been determined during numerous tests. The limit torques T_1 and T_2 and calculation example for the total torsional angle can be found in sections 3 and 4 of this documentation.
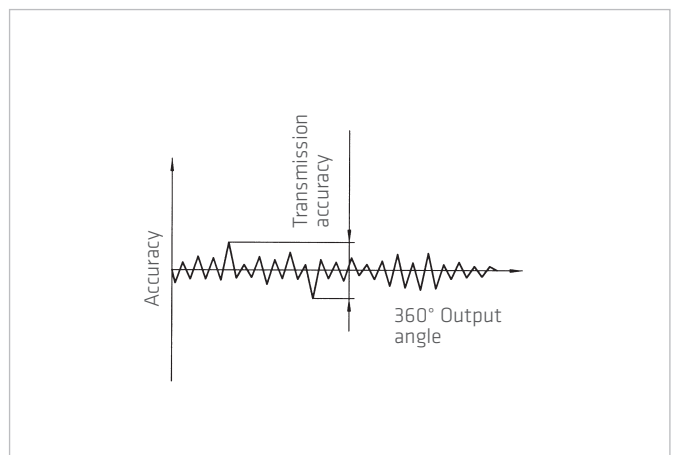

K_1, K_2, K_3 = Torsional stiffness, w = Output angle
$\varphi 1$ = Torsion angle, with output torque T_1
$\varphi 2$ = Torsion angle, with output torque T_2

Torsional stiffness
(Harmonic Planetary gears) K [Nm/rad]

The amount of elastic rotation at the output for a given torque and blocked input shaft. The torsional rigidity of the Harmonic Planetary gear describes the rotation of the gear above a reference torque of 15% of the rated torque. In this area the torsional stiffness is almost linear.

T_N = Rated torque
φ = Output angle

Transmission accuracy [arcmin]

The transmission accuracy of the gear represents the linearity error between input and output angle. The transmission accuracy is measured for one complete output revolution using a high resolution measurement system. The measurements are carried out without direction reversal. The transmission accuracy is defined as the sum of the maximum positive and negative differences between the theoretical and actual output rotation angles.

Weight m [kg]

The weight specified in the catalog is the net weight without packing and only applies to standard versions.

7.2 Labelling, Guidelines and Regulations

CE-Marking

With the CE marking, the manufacturer or EU importer declares in accordance with EU regulation, that by affixing the CE mark the product meets the applicable requirements in the harmonization legislation established the Community.

REACH Regulation

REACH is a European Community Regulation on chemicals. REACH stands for Registration, Evaluation, Authorization and Restriction of Chemicals.

RoHS EU Directive

The RoHS EU Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment.