Engineering Data
CobaltLine®-2UH Units

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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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.

Maximum torque capacity with extended temperature range

CobaltLine®-2UH Series Units are available in six sizes with gear ratios of 50, 80, 100, 120 and 160:1 offering repeatable peak torques from 23 to 841 Nm.

The output bearing with high tilting capacity often allows direct attachment of heavy payloads without the need for further support, thereby providing simple and space saving design installations.

They cover a wide torque range and feature long service life. If required, the Units are available as specific configurations tailored to your application. Standard servo motors can be attached in a compact manner. The CobaltLine® Series can be used for ambient temperatures between -40 °C and 90 °C.

3.2 Ordering Code

Table 9.1

Series	Size	Ratio[1]					Version	Special design
CobaltLine®	14	50	80	100			2UH	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		
Ordering code								
CobaltLine®	**25**		**100**			**2UH**		**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".

Table 9.2

Version	
Ordering code	**Description**
2UH	Unit with integrated cross roller output

Clarification of the technical data can be found in the Glossary

3.3 Technical Data

3.3.1 Generaly Technical Data

Table 10.1

	Unit	CobaltLine®-14-2UH			CobaltLine®-17-2UH			
Ratio	i [ ]	50	80	100	50	80	100	120
Repeatable peak toque	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} kgm²]	0.033			0.079			
Weight	m [kg]	0.52			0.68			

Table 10.2

	Unit	CobaltLine®-20-2UH					CobaltLine®-25-2UH				
Ratio	i [ ]	50	80	100	120	160	50	80	100	120	160
Repeatable peak toque	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} kgm²]	0.193					0.413				
Weight	m [kg]	0.98					1.5				

3.3.2 Dimensions

Illustration 11.1   CobaltLine®-14-2UH   [mm]

Illustration 11.2   CobaltLine®-17-2UH   [mm]
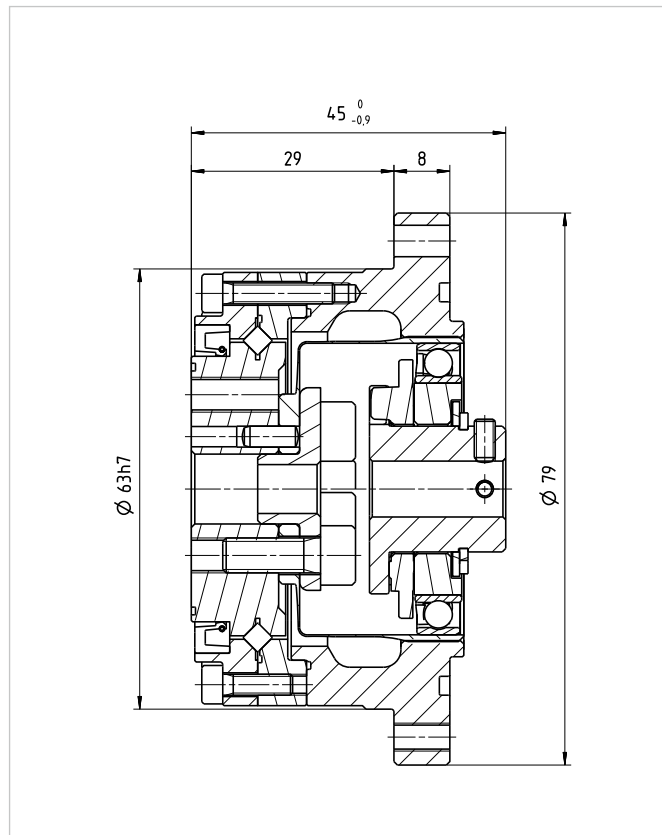
Illustration 11.3   CobaltLine®-20-2UH   [mm]
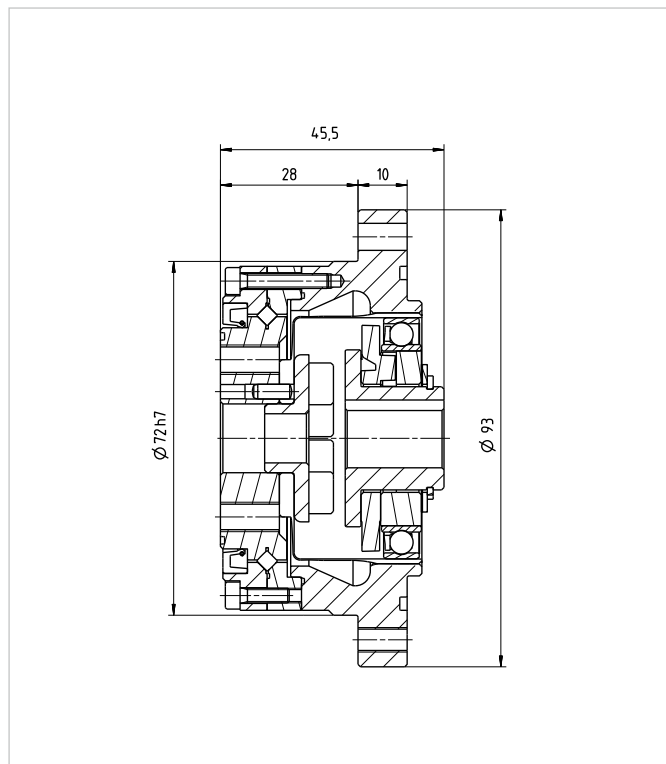
Illustration 11.4   CobaltLine®-25-2UH   [mm]
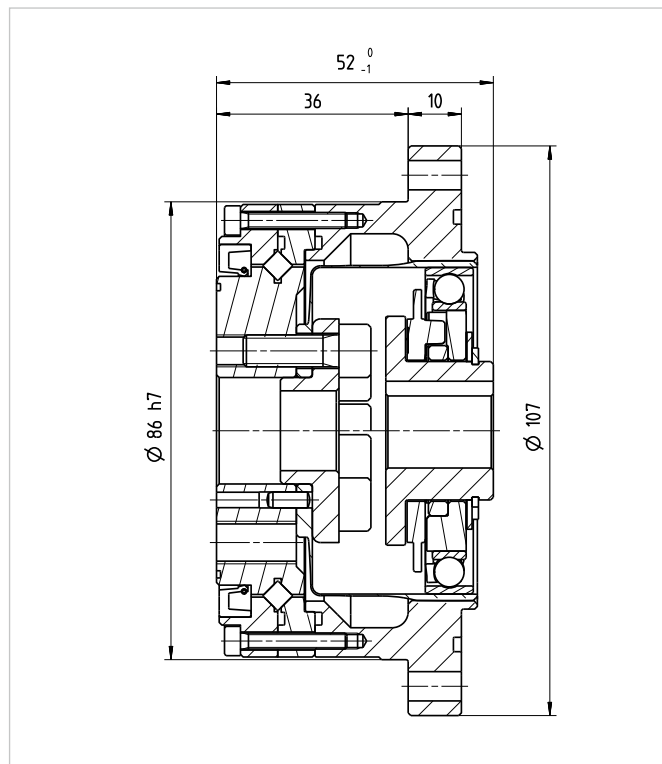
Table 12.1

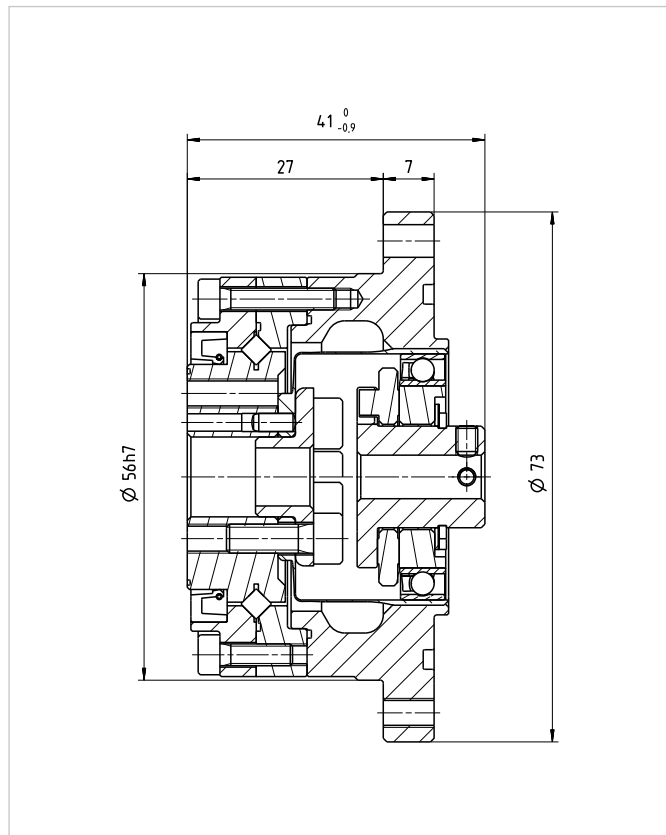|	Unit	CobaltLine®-32-2UH					CobaltLine®-40-2UH				
Ratio	i [ ]	50	80	100	120	160	50	80	100	120	160
Repeatable peak toque	T_R [Nm]	281	395	433	459	484	523	675	738	802	841
Average torque	T_A [Nm]	140	217	281	281	281	255	369	484	586	586
Rated torque	T_N [Nm]	99	153	178	178	178	178	268	345	382	382
Momentary peak torque	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]	1.96					4.5				
Weight	m [kg]	3.2					5.0				

Illustration 12.2   CobaltLine®-32-2UH   [mm]
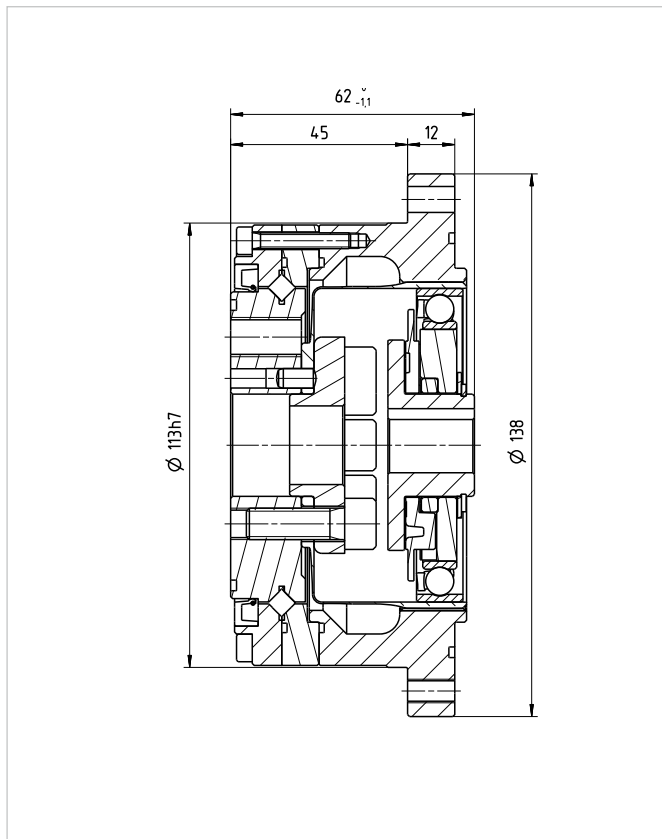
Illustration 12.3   CobaltLine®-40-2UH   [mm]
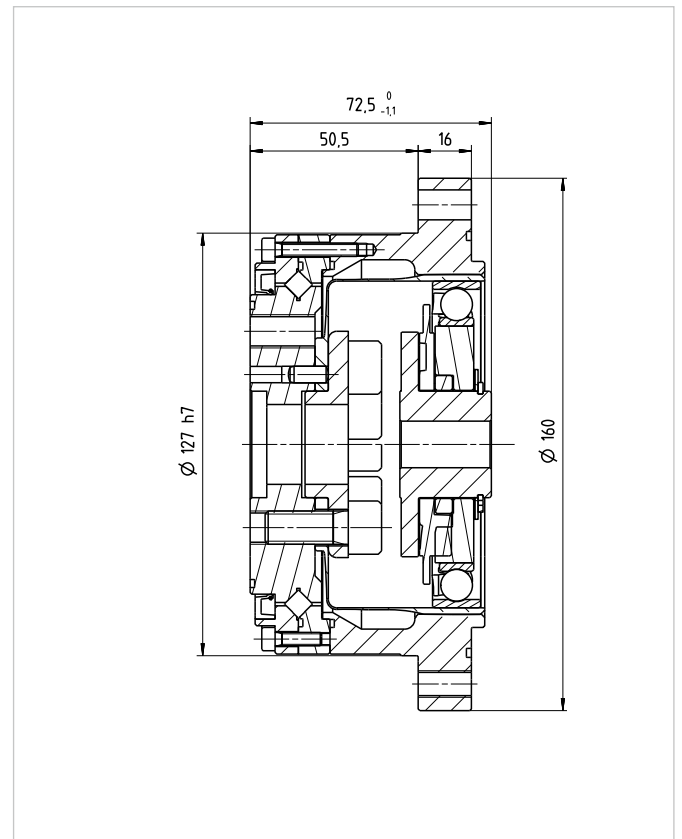
3.3.3 Minimum Housing Clearance

Table 13.1   [mm]

Size	14	17	20	25	32	40
X	6.0	4.5	3.5	4.0	3.5	4.0
ØZ	38	45	53	66	86	106

Illustration 13.2
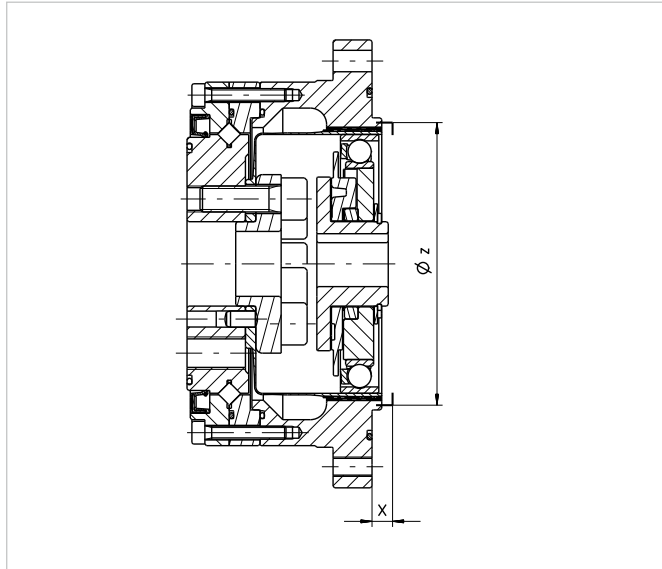
3.3.4 Accuracy

Table 13.3   [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 accuracy on request

3.3.5 Torsional Stiffness

Table 13.4

Size		14	17	20	25	32	40
T_1 [Nm]		2	3.9	7	14	29	54
T_2 [Nm]		6.9	12	25	48	108	196
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
	K_2[x10³ Nm/rad]	4.7	11	18	34	78	140
	K_1[x10³ Nm/rad]	3.4	8.1	13	25	54	100
i > 50	K_3[x10³ Nm/rad]	7.1	16	29	57	12	230
	K_2[x10³ Nm/rad]	6.1	14	25	50	11	200
	K_1[x10³ Nm/rad]	4.7	10	16	31	67	130

3.3.6 Bearings

Output Bearings

CobaltLine-2UH Units incorporate a high stiffness cross roller or four-point bearing to support output loads. This specially developed bearing can withstand high axial and radial forces as well as high tilting moments. The reduction gear is thus protected from external loads, so guaranteeing a long life and constant performance. The integration of an output bearing also serves to reduce design and production costs, by removing the need for additional output bearings in many applications.

However, in some applications the machine element to be driven requires additional bearing support. In this case, please take care to avoid overdetermination of the bearing arrangement. The cross roller bearing of the unit should be used as the fixed bearing, whilst the additional support bearing should be floating, if possible. Table 14.1 lists ratings and important dimensions for the output bearings.

Table 14.1

Size		14	17	20	25	32	40
Bearing type [1]		C	C	C	C	C	C
Pitch circle ø	d_p [m]	0.035	0.043	0.050	0.062	0.080	0.096
Offset [2]	R [m]	0.0095	0.0095	0.0095	0.0115	0.013	0.0145
Dynamic load rating	C [N]	4740	5290	5790	9600	15000	21300
Static load rating	C_0 [N]	6070	7550	9000	15100	25000	36500
Permissible dynamic tilting moment [3]	M [Nm]	41	64	91	156	313	450
Permissible static tilting moment [4]	M_0 [Nm]	53	80	113	234	500	876
Tilting moment stiffness [6]	K_B [Nm/arcmin]	13	22.5	37	70	157	265
Permissible axial load [5]	F_a [N]	3374	3207	3511	5827	7926	11242
Permissible radial load [5]	F_r [N]	2256	2148	2354	3904	6101	8652

Normally, the gear life is determined by the life of the Wave Generator bearing. Depending on the specific load conditions the output bearing can also be determinant for the unit life.
1)   F = Four-point bearing, C = Cross roller bearing
2)   See illustration 14.2
3)   These values are valid for moving gears. They are not based on the equation for lifetime calculation of the output bearing but on the maximum allowable deflection of the Harmonic Drive® component set. The values indicated in the table must not be exceeded even if the lifetime equation of the bearing permits higher values.
4)   These values are valid for gears at a standstill and for a static load safety factor f_s = 1.8 for # 14-20 and 1,5 for # 25-58. For other values of f_s, please refer to section 4.6.
5)   These data are valid for n = 15 rpm and L_{10}=15000h
3) 4) 5) These data are only valid if the following conditions are fulfilled:
      For: M, M_0 : F_a = 0, F_r = 0 | F_a : M = 0; F_r = 0 | F_r : M = 0, F_a = 0
6)   Average value

Illustration 14.2

$$M = F_r * (L_r + R) + F_a * L_a$$
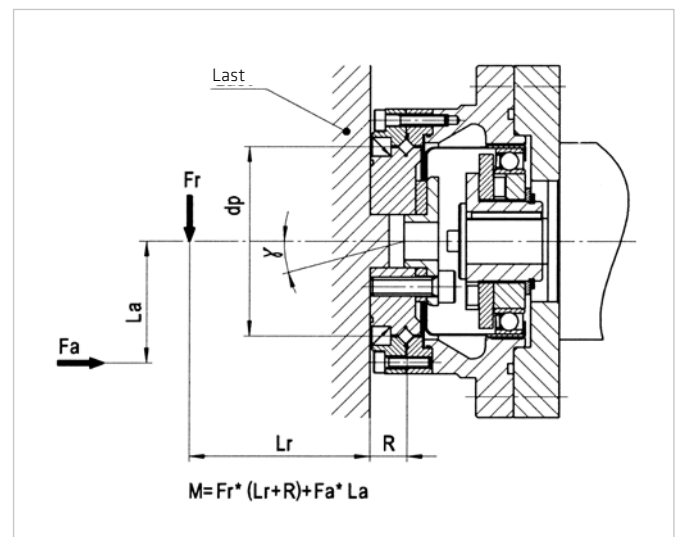
Output Bearing and Housing Tolerances

Table 15.1 [mm]

Size	14	17	20	25	32	40
a	0.010	0.010	0.010	0.015	0.015	0.015
b	0.010	0.012	0.012	0.013	0.013	0.015
c	0.024	0.026	0.038	0.045	0.056	0.060
d	0.010	0.010	0.010	0.010	0.010	0.015
e	0.038	0.038	0.047	0.049	0.054	0.060

Illustration 15.2
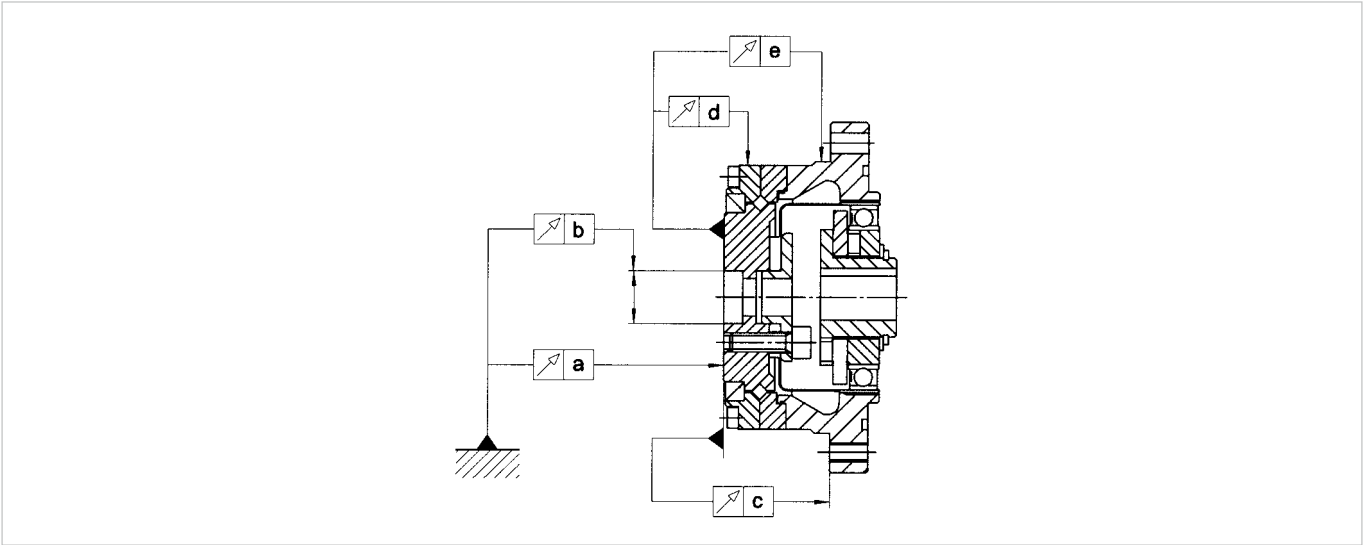
3.3.7 Materials Used

Materials:
Housing: Cast iron and bearing steel.
Adapter flange, if supplied by Harmonic Drive AG: high tensile aluminium or steel.

Surfaces:
Screws: Black phosphatized.
Housing: Bright.
Output bearing: Bright bearing steel.

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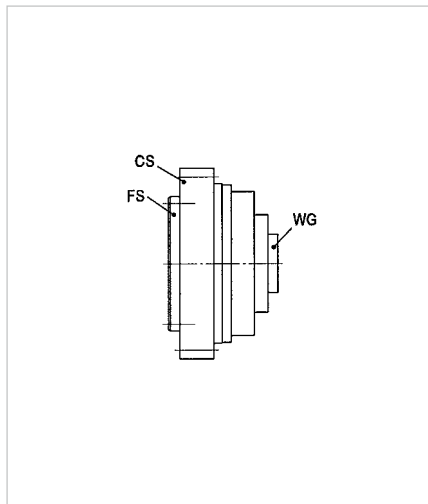
The values for ratios of Harmonic Drive® gears refer to the standard input and output arrangement (example 1 in the table below). Other arrangements are possible, and also shown in the table.

Ratio

1)
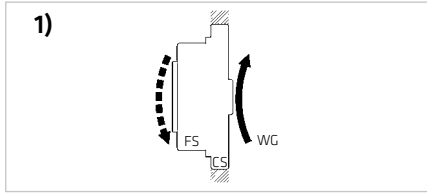
Reduction gearing
CS Fixed
WG Input
FS Output

Equation 17.1

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

Input and output rotate in opposite directions.

2)
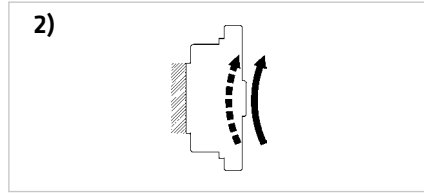
Reduction gearing
FS Fixed
WG Input
CS Output

Equation 17.2

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

Input and output rotate in same direction.

3)
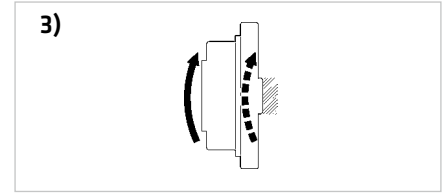
Reduction gearing
WG Fixed
FS Input
CS Output

Equation 17.3

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

Input and output rotate in same direction.

4)
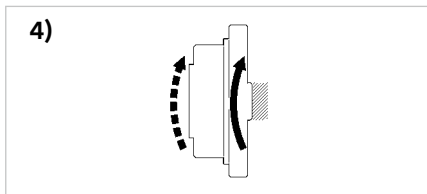
Speed increaser gearing
WG Fixed
CS Input
FS Output

Equation 17.4

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

Input and output rotate in same direction.

5)
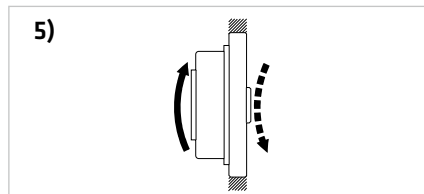
Speed increaser gearing
CS Fixed
FS Input
WG Output

Equation 17.5

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

Input and output rotate in opposite directions.

6)
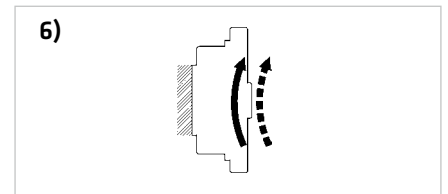
Speed increaser gearing
FS Fixed
CS Input
WG Output

Equation 17.6

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

Input and output rotate in same direction.

7)
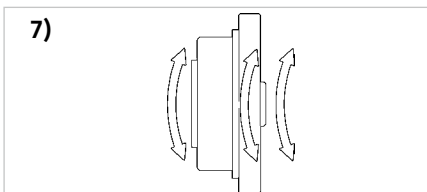
Differential gear
WG Control input
CS Main drive input
FS Main drive output

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.

ADVICE

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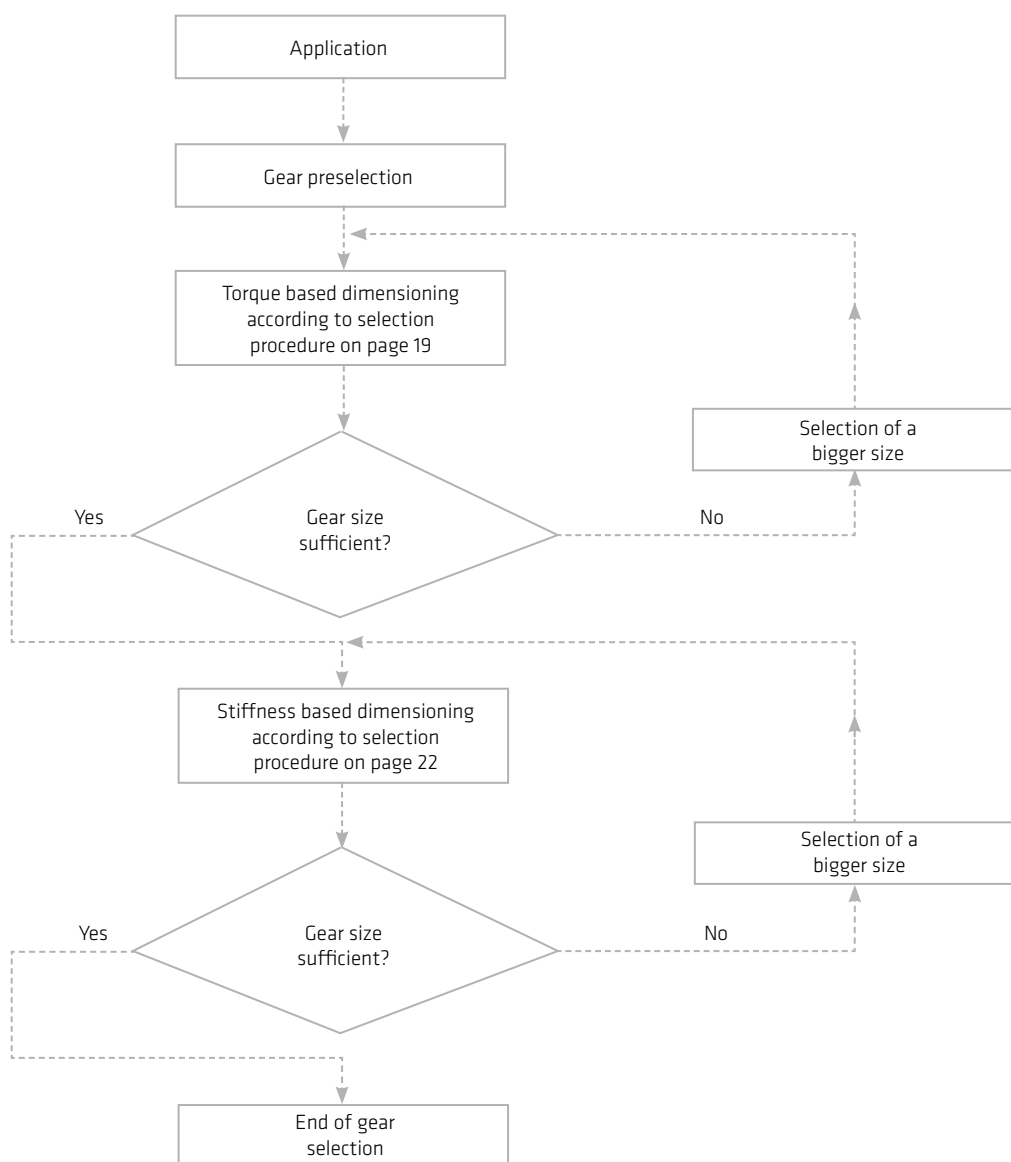
4.1.1 Torque Based Dimensioning

Output Data

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

Illustration 19.1
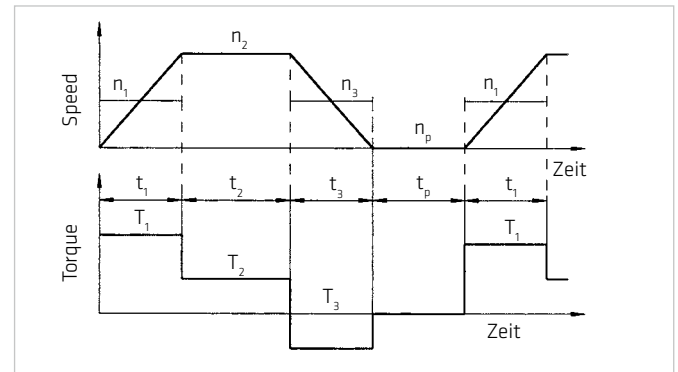
Equation 19.2

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

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

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

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

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
(s. 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

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

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 [2000 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

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

f_n = Resonance frequency [Hz]
K_1 = Gear torsional stiffness K_1 [Nm/rad]
J = Load moment of inertia [kgm²]

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

$n_n = f_n * 30$ [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 kgm². 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:
$n_n = 30*30 = 900$ [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 $K_1 = 6.7 \cdot 10^4$ Nm/rad

T_1 = 29 Nm $K_2 = 1.1 \cdot 10^5$ Nm/rad

T_2 = 108 Nm $K_3 = 1.2 \cdot 10^5$ 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 5.7.2.

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]

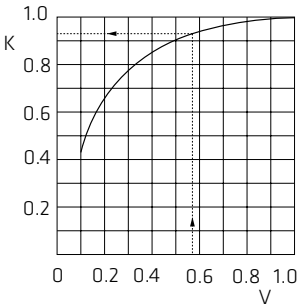| Sizes		14	17	20	25	32	40	45	50	58
Ratio	30	60	33	28	28	23	–	–	–	–
	50	36	20	17	17	14	14	12	12	10
	80	23	13	11	11	9	9	8	8	6
	100	18	10	9	9	7	7	6	6	5
	120	–	8	8	8	6	6	5	5	4
	160	–	–	6	6	5	5	4	4	3

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 these pages.

4.4.1 Efficiency Calculations

Table 25.1

Calculation Procedure	Example
	Efficiency of HFUC-20-80-2A-GR with input speed n=1000 rpm ouput 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. $V = \dfrac{T_{av}}{T_N}$ [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 $V = \dfrac{19.6 \text{ Nm}}{34.0 \text{ Nm}} = 0.57$
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
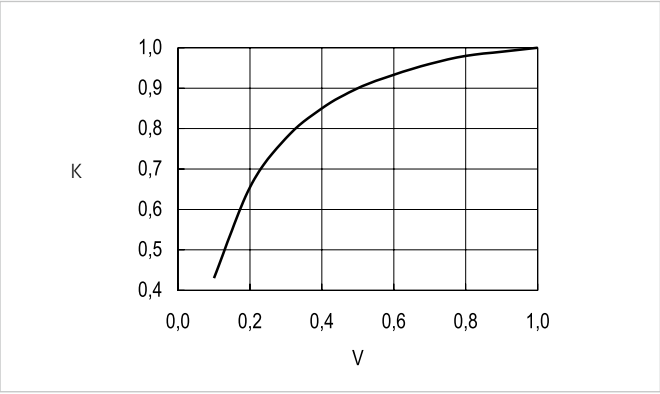
4.4.2 Efficiency Tables

Efficiency for grease lubrication at rated torque Harmonic Drive® grease

Size 14

Illustration 26.1

Size 17 - 90

Illustration 27.1

Ratio= 30

Efficiency [%] vs Temperature [°C]
Curves: 500 rpm, 1000 rpm, 2000 rpm, 3500 rpm

Ratio= 50

Efficiency [%] vs Temperature [°C]
Curves: 500 rpm, 1000 rpm, 2000 rpm, 3500 rpm

Ratio= 80, 100

Efficiency [%] vs Temperature [°C]
Curves: 500 rpm, 1000 rpm, 2000 rpm, 3500 rpm

Ratio= 120

Efficiency [%] vs Temperature [°C]
Curves: 500 rpm, 1000 rpm, 2000 rpm, 3500 rpm

Ratio= 160

Efficiency [%] vs Temperature [°C]
Curves: 500 rpm, 1000 rpm, 2000 rpm, 3500 rpm
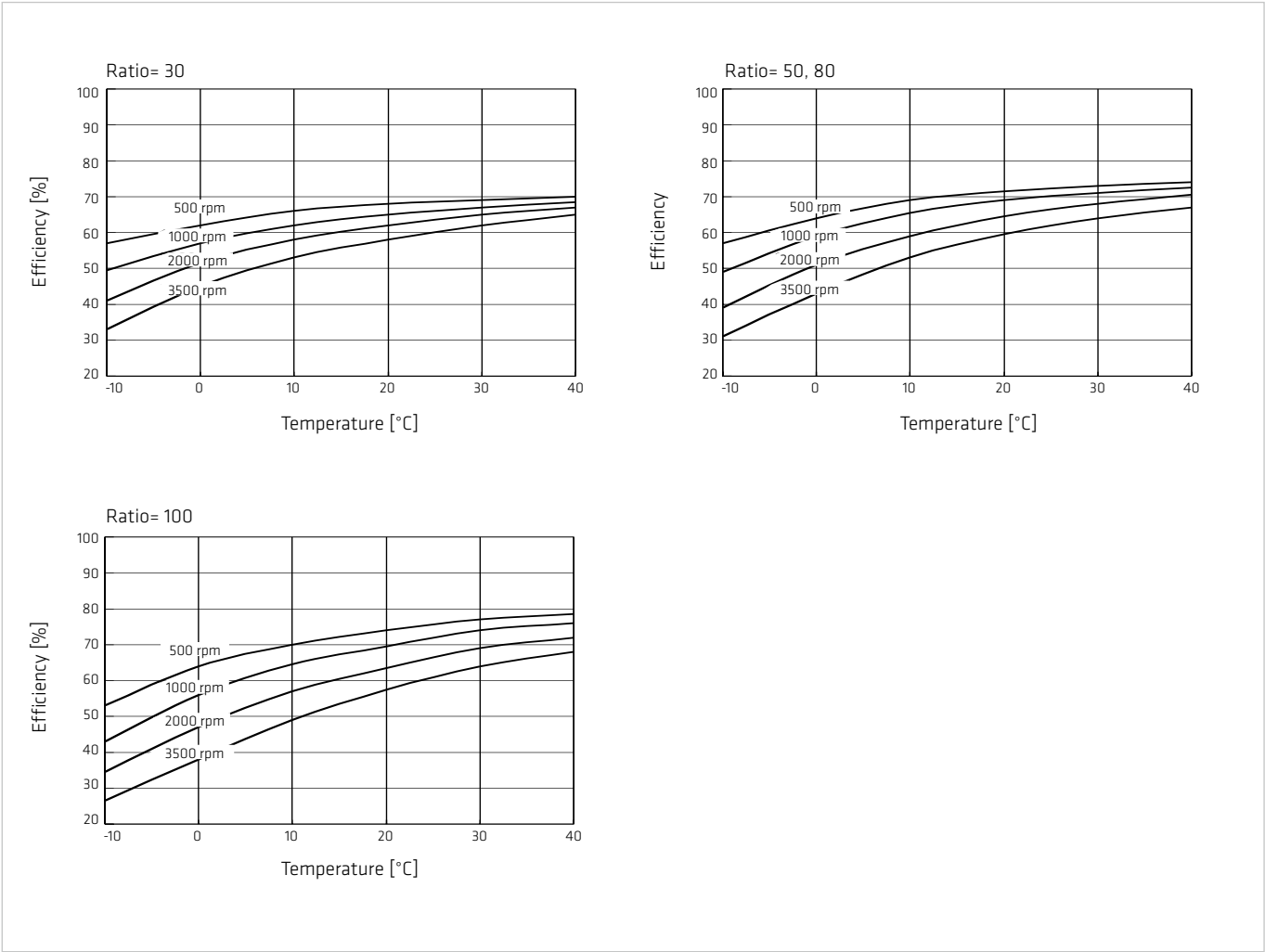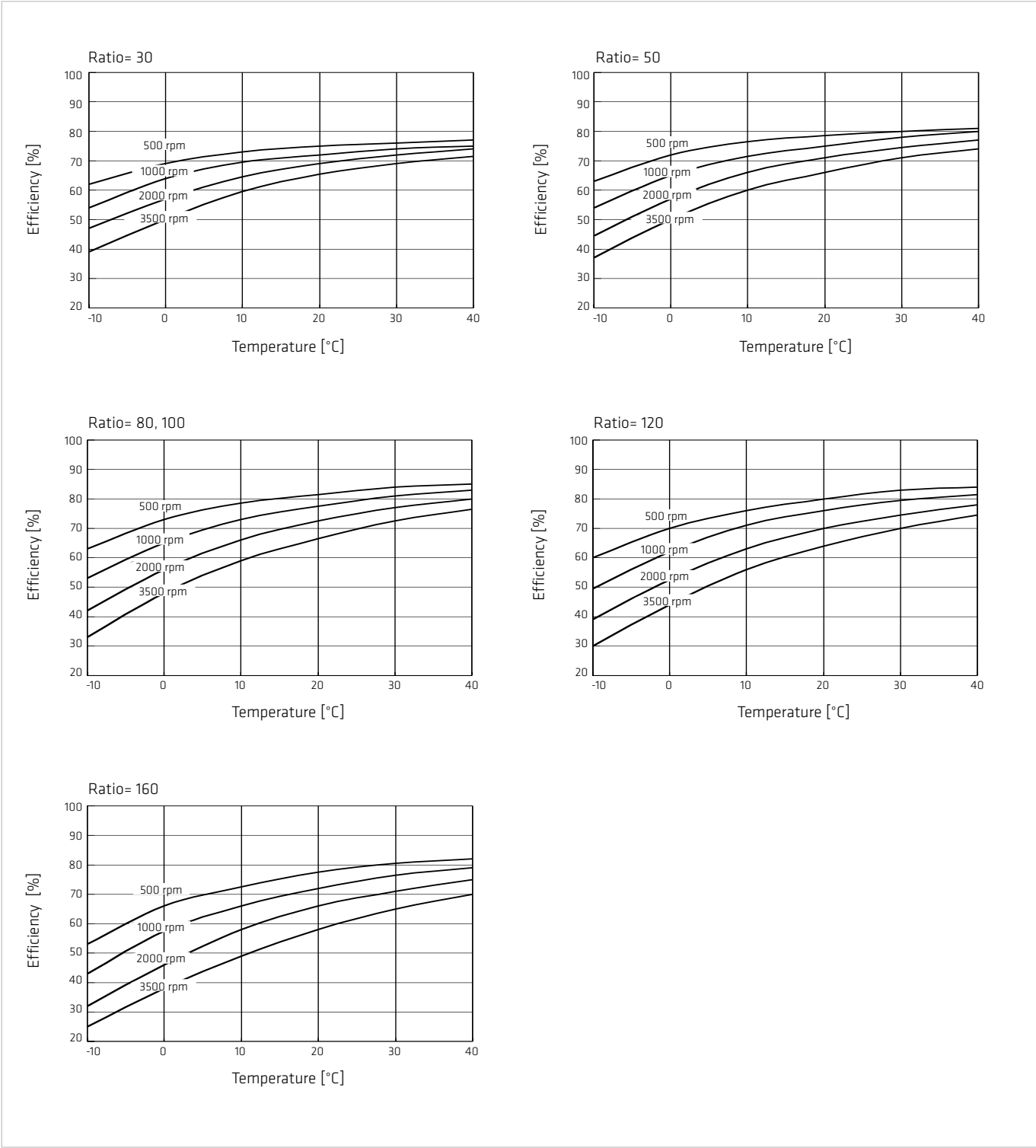
4.5 No Load Starting-, Back Driving- and Running Torque

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
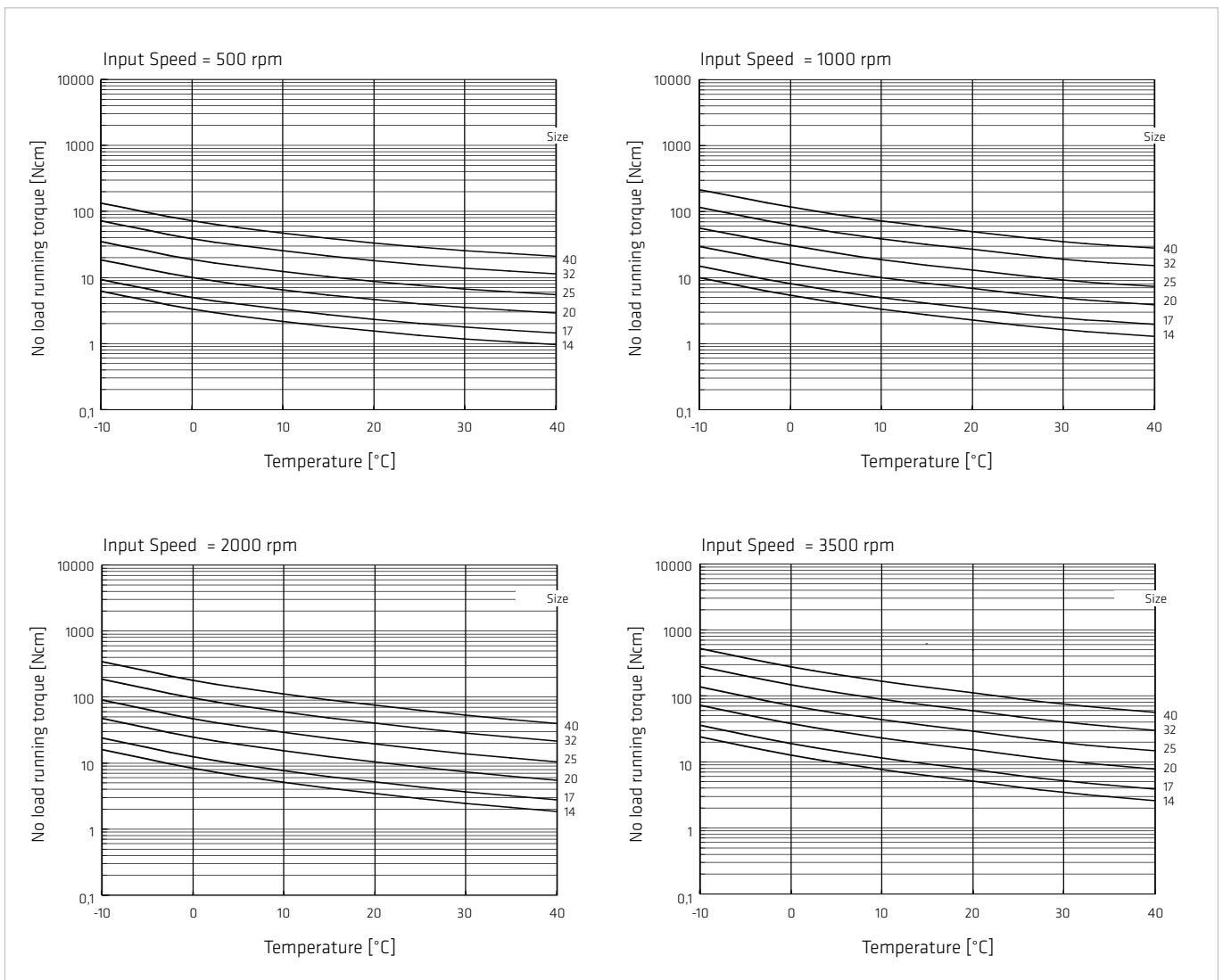Gear ratio i = 100
For other ratios please apply the compensation values below.
For oil lubrication please contact Harmonic Drive AG.

4.5.1 No Load Running Torque

Illustration 28.1

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 29.1 [Ncm]

Ratio	Size					
	14	17	20	25	32	40
30	2.5	3.8	5.4	8.8	16.0	–
50	1.1	1.6	2.3	3.8	7.1	12
80	0.2	0.3	0.5	0.7	1.3	2.1
120	–	-0.2	-0.3	-0.5	-0.9	-1.5
160	–	–	-0.8	-1.2	-2.2	-3.5

4.5.2 No Load Starting Torque

Table 29.2 [Ncm]

Ratio	Size					
	14	17	20	25	32	40
30	6.4	9.3	15	25	54	–
50	4.1	6.1	7.8	15	31	55
80	2.8	4.0	4.9	9.2	19	35
100	2.5	3.4	4.3	8.0	18	31
120	–	3.1	3.8	7.3	15	28
160	–	–	3.3	6.3	14	24

4.5.3 No Load Back Driving Torque

Table 29.3 [Nm]

Ratio	Size					
	14	17	20	25	32	40
30	2.4	3.8	6.2	11	23	–
50	1.6	3.0	4.7	9.0	18	33
80	1.6	3.0	4.8	9.1	19	33
100	1.8	3.3	5.1	9.8	20	36
120	–	3.5	5.5	11	22	39
160	–	–	6.4	13	26	46

4.6 Life for Continuous Operation

The operating life of the output bearing can be calculated using equation 30.1.

Equation 30.1

$$L_{10} = \frac{10^6}{60 \cdot n_{av}} \cdot \left(\frac{C}{f_w \cdot P_c} \right)^B$$

with:

L_{10} [h]	=	Operating life
n_{av} [rpm]	=	Average output speed (equation 30.2)
C [N]	=	Dynamic load rating see table "Output Bearing Ratings"
P_c [N]	=	Dynamic equivalent load (equation 31.1)
f_w	=	Operating factor (table 30.3)
B	=	Bearing type (table 30.4)

Average Output Speed

Equation 30.2

$$n_{av} = \frac{|n_1| t_1 + |n_2| t_2 + \ldots + |n_n| t_n}{t_1 + t_2 + \ldots + t_n + t_p}$$

Table 30.3

Load conditions	f_w
No impact loads or vibrations	1 …1.2
Normal rotating. normal loads	1.2 … 1.5
Impact loads and/or vibrations	1.5 … 3

Table 30.4

Bearing type	B
Cross roller bearings	10/3
Four point contact bearings	3

Dynamic Equivalent Load

Equation 31.1

$$P_C = x \cdot \left(F_{rav} + \frac{2M}{d_p} \right) + y \cdot F_{aav}$$

with:

F_{rav} [N]	=	Radial force (equation 31.2)	x	=	Radial load factor (table 31.4)
F_{aav} [N]	=	Axial force (equation 31.3)	y	=	Axial load factor (table 31.4)
d_p [m]	=	Pitch circle (see table 14.1)	M	=	Tilting moment

Equation 31.2

$$F_{rav} = \left(\frac{|n_1| \cdot t_1 \cdot (|F_{r1}|)^B + |n_2| \cdot t_2 \cdot (|F_{r2}|)^B + \dots + |n_n| \cdot t_n \cdot (|F_{rn}|)^B}{|n_1| \cdot t_1 + |n_2| \cdot t_2 + \dots + |n_n| \cdot t_n} \right)^{1/B}$$
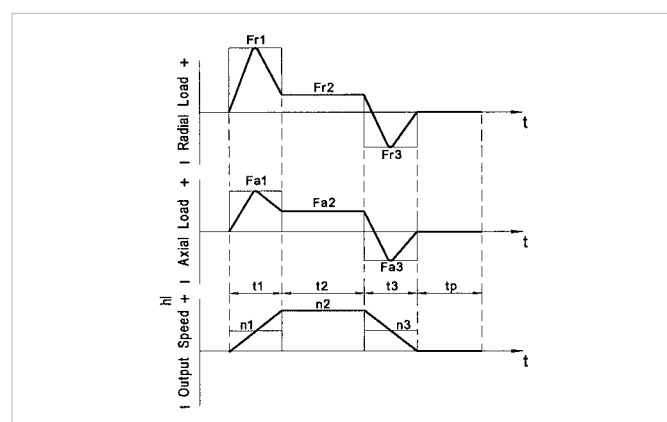
Equation 31.3

$$F_{aav} = \left(\frac{|n_1| \cdot t_1 \cdot (|F_{a1}|)^B + |n_2| \cdot t_2 \cdot (|F_{a2}|)^B + \dots + |n_n| \cdot t_n \cdot (|F_{an}|)^B}{|n_1| \cdot t_1 + |n_2| \cdot t_2 + \dots + |n_n| \cdot t_n} \right)^{1/B}$$

Table 31.4

Load factors	x	y
$\dfrac{F_{aav}}{F_{rav} + 2 \cdot M / d_p} \leq 1.5$	1	0.45
$\dfrac{F_{aav}}{F_{rav} + 2 \cdot M / d_p} > 1.5$	0.67	0.67

Illustration 31.5

Please note:

F_{rx} = represents the maximum radial force.
F_{ax} = represents the maximum axial force.
t_p = represents the pause time between cycles.

4.6.1 Output Bearing at Oscillating Motion

Life for Oscillating Motion

The operating life at oscillating motion can be calculated using equation 32.1

Equation 32.1

$$L_{OC} = \frac{10^6}{60 \cdot n_1} \cdot \frac{180}{\varphi} \cdot \left(\frac{C}{f_w \cdot P_c} \right)^B$$

with:

|		
L_{OC} [h]	=	Operating life for oscillating motion
n_1 [cpm]	=	Number of oscillations/minute*
C [N]	=	Dynamic load rating, see table "Output Bearing" in the appropriate product chapter (table 14.1)
P_c [N]	=	Dynamic equivalent load (equation 31.1)
φ [deg]	=	Oscillating angle
f_w	=	Operating factor (table 30.3)

* one oscillation means 2φ

Oscillating angle

At oscillating angles < 5° fretting corrosion may occur due to insufficient lubrication.
In this case please contact our sales engineer for counter measures.

Illustration 32.2
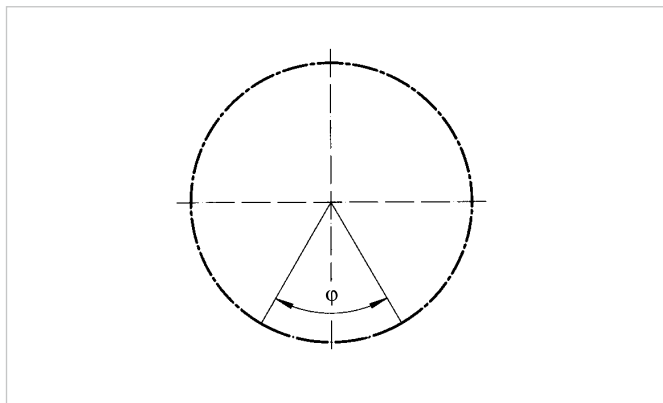
4.7 Permissible Static Tilting Moment

In case of static load, the bearing load capacity can be determined as follows:

Equation 33.1

$$f_s = \frac{C_0}{P_0} \quad \text{mit} \quad P_0 = x_0 \left(F_r + \frac{2M}{d_p} \right) + y_0 \cdot F_a$$

and so

Equation 33.2

$$M_0 = \frac{d_p \cdot C_0}{2 \cdot f_s}$$

f_s = Static load safety factor
(f_s = 1.5 … 3) (table 33.3)

C_0 = Static load rating

F_r = F_a = 0

x_0 = 1

y_0 = 0.44

P_0 = Static equivalent load (equation 33.1)

d_p = Pitch circle diameter of the output bearing (table 14.1)

M = Moment acting (illustration 14.2)

M_0 = Allowable static overturning moment

Table 33.3

Rotation conditions of bearing	Lower limit value for fs
Normal	≥ 1.5
Vibrations / Impacts	≥ 2
High transmission accuracy	≥ 3

4.8 Angle of Inclination

The angle of inclination of the output flange, as a function of the tilting moment acting on the output bearing, can be calculated by means of equation 33.4:

Equation 33.4

$$\gamma = \frac{M}{K_B}$$

with:
γ [arcmin] = Angle of inclination of the output flange
M [Nm] = Tilting moment acting on the output bearing
K_B [Nm/arcmin] = Moment stiffness of the output bearing (table 14.1)

4.9 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.

4.9.1 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 34.1 and 34.2.

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 34.1

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

Table 34.2

	Ratio = 30						
Grease	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 35.1 gives some important information regarding Harmonic Drive® lubricating greases.

Table 35.1

| 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 and technical data sheets for the Harmonic Drive® lubricants are available from Harmonic Drive AG.

Special Operating Demands

Table 36.1 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 36.1

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 applications. 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.

4.9.2 Oil Lubrication

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

Table 36.2

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 5.5.5.

4.10 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 37.1
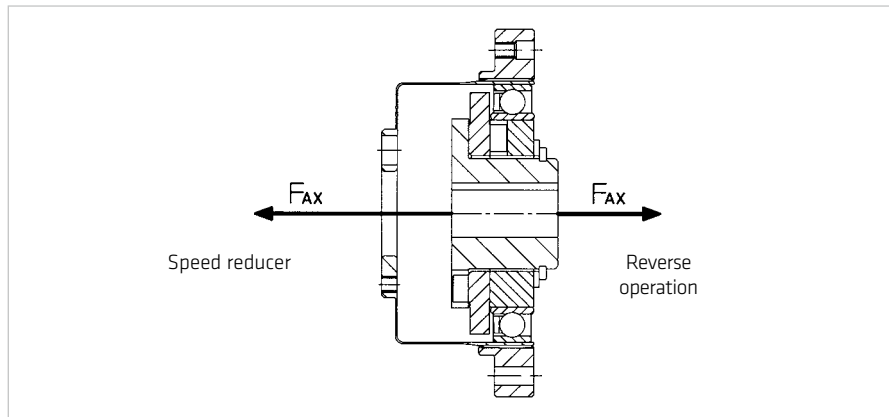
Table 37.2

Ratio		
30	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 32°$	[Equation 37.3]
50	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 30° + 2\mu PF$	[Equation 37.4]
80...160	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 20° + 2\mu PF$	[Equation 37.5]

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

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

$$F_{AX} = 215 \text{ N}$$

Table 37.6

Sizes	14	17	20	25	32	40	50
2µPF [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.

Gears with Grease Lubrication
Units are supplied with grease lubricant as standard.

Gears with Oil Lubrication
Harmonic Drive® Units with oil lubrication are generally customer-specific solutions. Please follow the notes given on the confirmation drawing. 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.

5.3 Assembly Information

ADVICE

Screws which have been tightened by the gear manufacturer must not be loosened.

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 39.2 are observed for the input assembly.
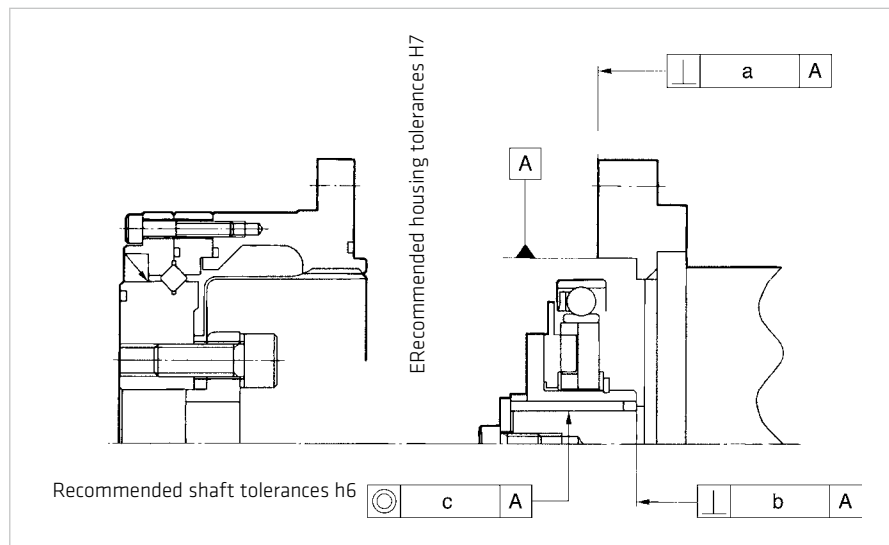
Illustration 39.1

Table 39.2 [mm]

Size	14	17	20	25	32	40
a	0.011	0.015	0.017	0.024	0.026	0.026
b	0.017	0.020	0.020	0.024	0.024	0.032
	(0.008)	(0.010)	(0.010)	(0.012)	(0.012)	(0.012)
c	0.030	0.034	0.044	0.047	0.050	0.063
	(0.016)	(0.018)	(0.019)	(0.022)	(0.022)	(0.024)

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.
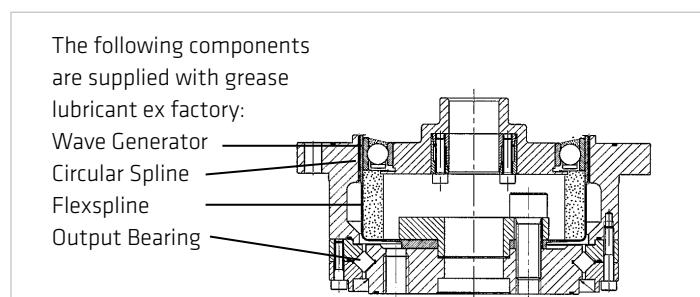
5.5 Lubrication

Harmonic Drive® Units are delivered ready for immediate installation. They are supplied with lifetime lubricant which is a high performance grease that meets the specific requirements of the Harmonic Drive® gears. It guarantees constant accuracy of the gears for their whole life. A re-lubrication of the Units is not necessary.

5.5.1 Grease Lubrication

Units are supplied with standard grease lubricant. Illustration 39.3 shows the sections where lubrication is required and which are filled with grease lubrication at the time of delivery. If no special arrangements are made the specially developed high perfomance grease 4BNo.2 is used. If any other grease is used this will be indicated on the customer drawing.
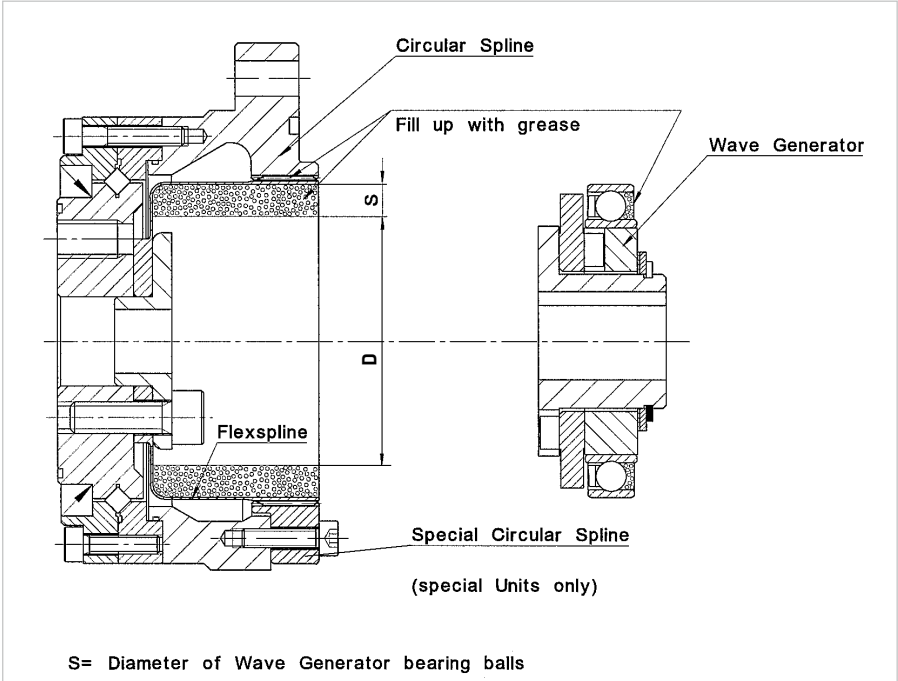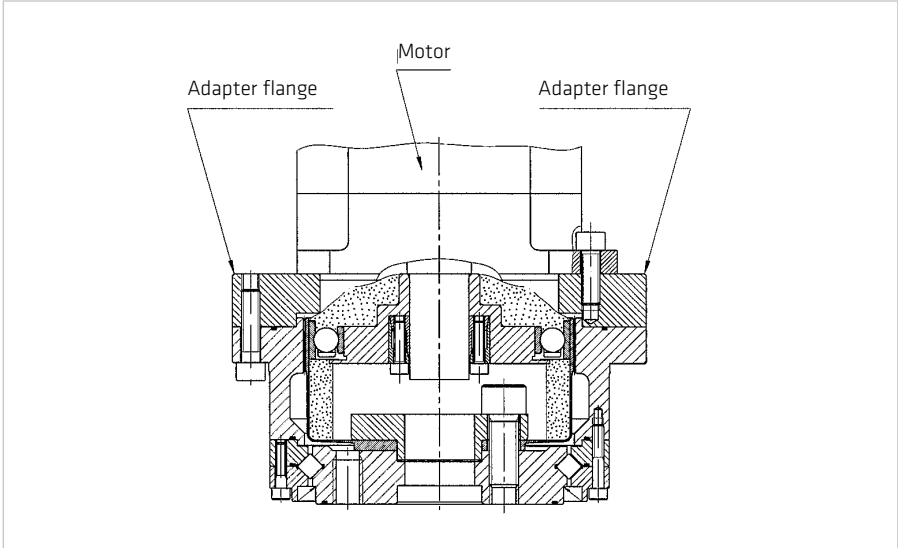
Illustration 39.3

The following components
are supplied with grease
lubricant ex factory:
Wave Generator
Circular Spline
Flexspline
Output Bearing

5.5.2 Amount of Grease

Illustration 40.1

S= Diameter of Wave Generator bearing balls

Table 40.2 [mm]

Size	14	17	20	25	32	40
D	28	33	40	50	66	79
S	3	4	4.5	5.5	7	9.5

Illustration 40.3

5.5.3 Additional Grease Package

When the unit is mounted to the motor with the adaptor flange design recommended by Harmonic Drive AG, the unit can be used in all operating positions. To achieve the maximum gear life, we recommend that an additional grease package is provided in the grease reservoir between Wave Generator and motor d-shield during assembly, see illustration 41.2

Table 41.1

Size		14	17	20	25	32	40
Standard grease quantity	ca. [g]	5.5	10	16	40	60	130
	ca. [cm³]	6	11	18	44	66	143
Additionally required grease quantity for operation with Wave Generator above	ca. [g]	3	4	9	13	22	44
	ca. [cm³]	3	5	9	14	24	49

Illustration 41.2

Illustration 41.3

Operating Positions

Wave Generator below

Wave Generator vertical

Wave Generator above
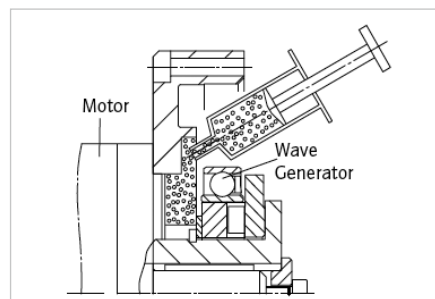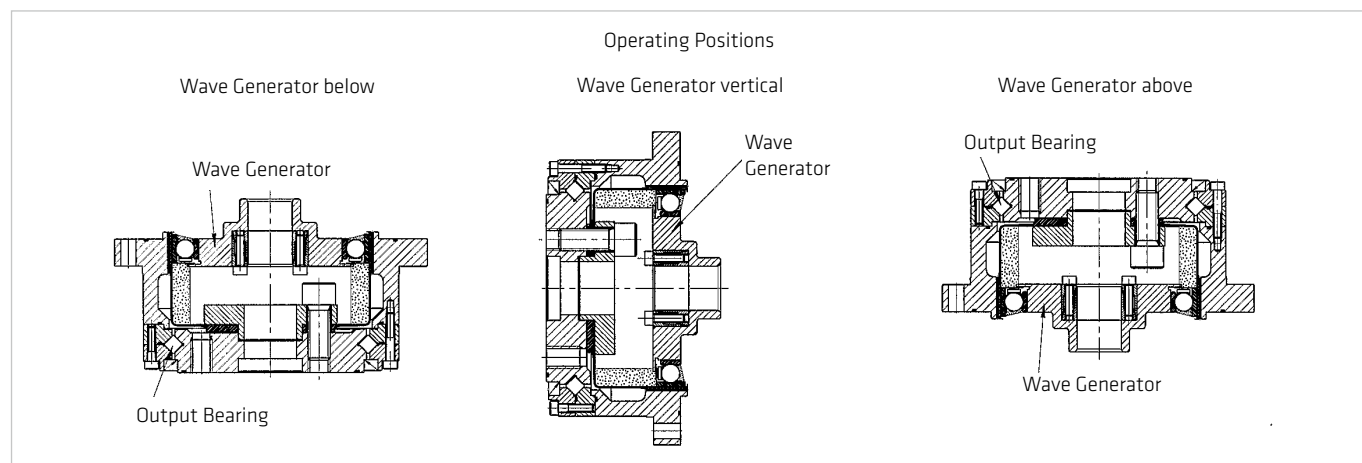
Table 41.4 [kg]

Ordering code	Available packaging
Special grease SK-1A. SK-2	0.5; 2.5; 16
Special grease 4BNo.2	0.5; 2; 16
Special grease Flexolub-A1	1.0; 25

5.5.4 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 42.1 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 42.1
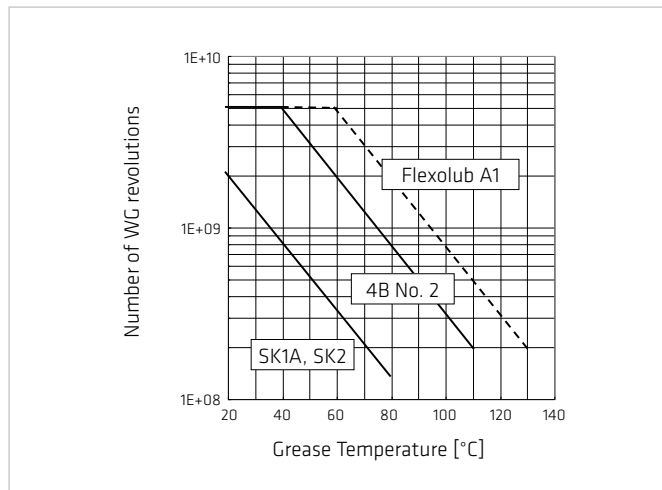
Gleichung 42.2

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

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

L_{GTn} = see diagram

T_N = Rated torque

T_{av} = Average torque

5.5.5 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 section 4.9.2 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.

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.

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. Permitted oil types see in table 36.2. The mixture of lubricants of different specifications should generally be avoided.

5.6 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 in table 8 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. Flanges provided with O-ring grooves must be sealed with sealing compound when a proper seal cannot be achieved using the O-ring alone.

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.

5.7 Assembly

5.7.1 Motor Assembly

The Units have been designed for simple motor assembly. This means that the Wave Generator is mounted directly on the motor shaft. When ordering please indicate which motor type is to be used, so that the Wave Generator can be manufactured to match. If required, units can be provided including the motor adaptor flange or with a ready assembled motor. In addition to the correct dimensioning of the motor, particular attention must be paid to the geometric tolerances of the motor output flange and motor shaft. The shaft and flange tolerances of the motor should fulfill the requirements of the DIN 42955 standard. To fully exploit the excellent performance characteristics of the units we recommend the use of motors fulfilling DIN 42955 R tolerances.

Adaptor Flange

The transmission accuracy of the gearbox is dependent on the manufacturing accuracy of the motor adaptor flange. Table 44.2 shows the recommended tolerances for the motor with assembled adaptor flange.

Illustration 44.1

Recommended shaft tolerances k6
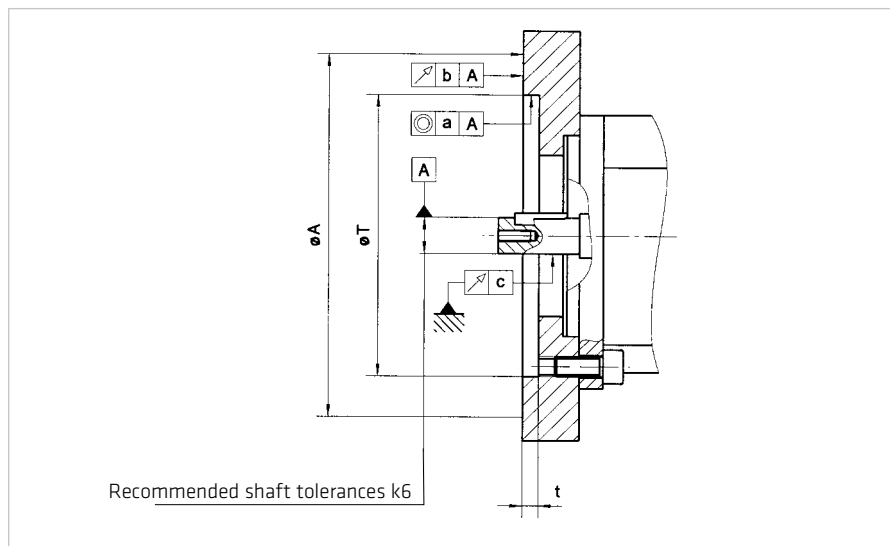
ADVICE

For the manufacturing of the adaptor flange we recommend the dimensions and tolerances given in table 44.2. To achieve the given value for concentricity and run out we recommend that the motor- and gear side flange surfaces are manufactured at a single clamping.

Table 44.2

| Size	14	17	20	25	32	40
a	0.030	0.040	0.040	0.040	0.040	0.050
b	0.030	0.040	0.040	0.040	0.040	0.050
c	0.015	0.015	0.018	0.018	0.018	0.018
Ø A	73	79	93	107	138	160
t	3	3	4	4	4	5
Ø T H7	38	48	56	67	90	110

Mounting

As shown in illustration 45.2 and 45.3, there are two basic methods of assembly. Table 45.1 provides recommendations concerning the appropriate assembly procedure.

Table 45.1 [mm]

Size	14	17	20	25	32	40	Assembly according to illustration
Motor-Centering - ø	<35.5	<43.5	<50.0	<62.5	<81.5	<100.0	45.2
	≥35.5	≥43.5	≥50.0	≥62.5	≥81.5	≥100.0	45.3

Illustration 45.2
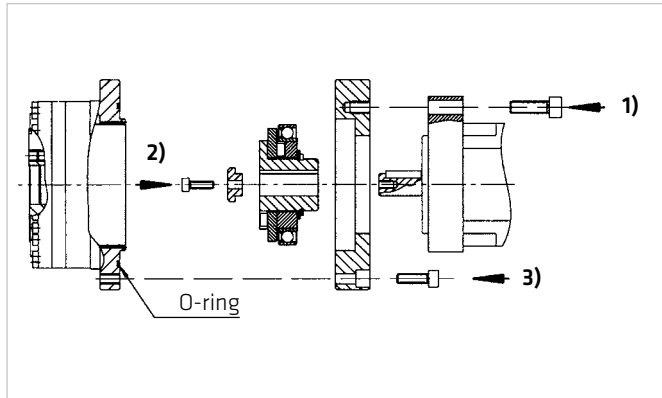
Installation steps as shown in illustration 45.2:

1) Mount the flange assembly to the motor.
2) Mount the Wave Generator to the motor shaft.
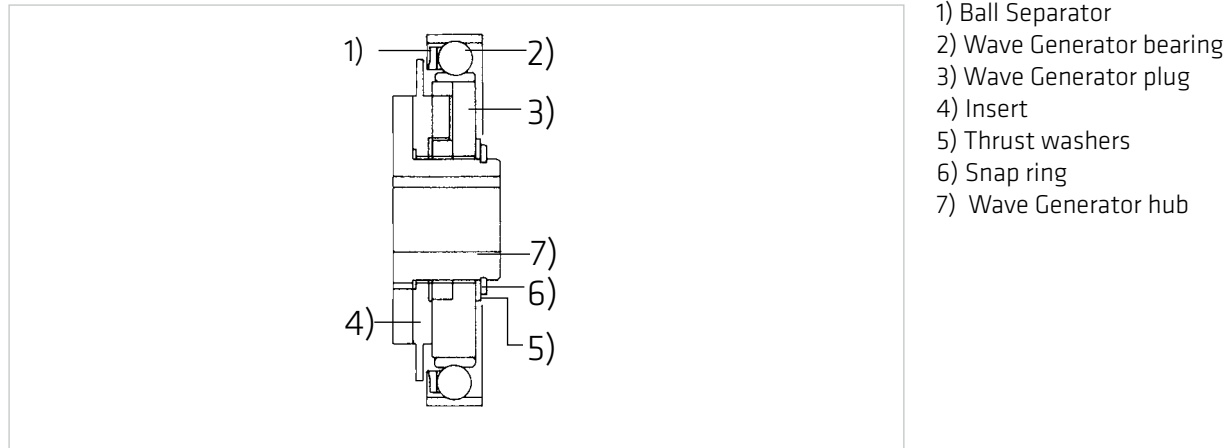3) Installation of the flange including motor onto the unit.

Illustration 45.3
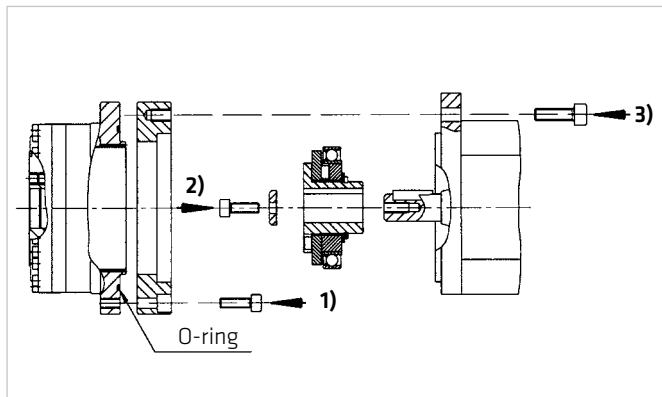
Installation steps according to illustration 45.3:

1) Mount the flange to the Unit.
2) Mount the wave generator to the motor shaft.
3) Mount the motor onto the flange.

5.7.2 Wave Generator Components

Illustration 46.1 shows a standard Wave Generator with Oldham Coupling.

Illustration 46.1

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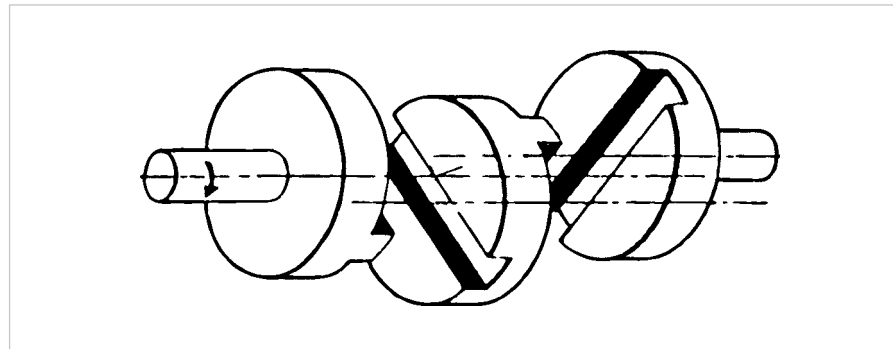5) Thrust washers
6) Snap ring
7) Wave Generator hub

Wave Generator Modifications

CobaltLine-2UH units are provided with an Oldham coupling to compensate for eccentricity of the input shaft see illustration 46.2.

Principle of an Oldham Coupling

Illustration 46.2

Bore Diameter for Solid Wave Generator

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 47.2. Use of a Solid Wave Generator demands tighter tolerances for the motor shaft

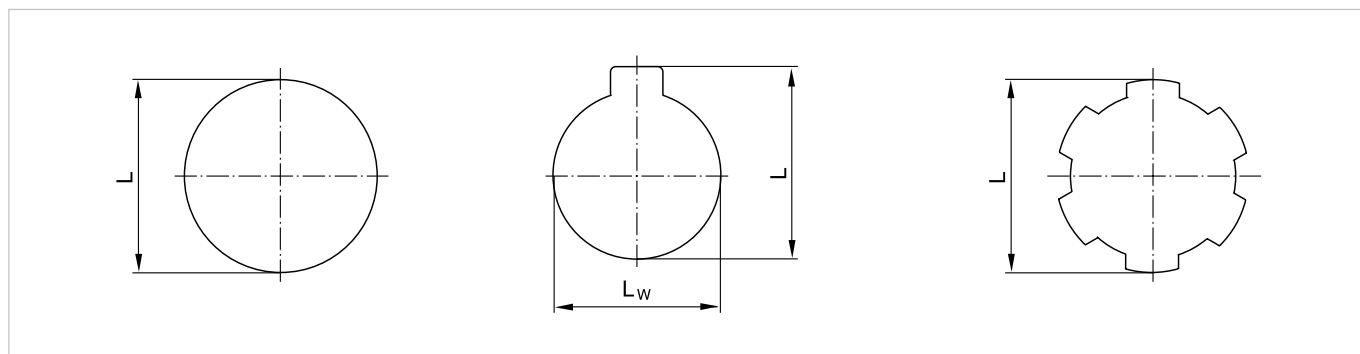## Maximum Bore Biameter without Oldham Coupling

Illustration 47.1

Table 47.2   [mm]

Size	14	17	20	25	32	40
L_W for keys to DIN 6885 T1	12	13	17	22	28	34
L	17	20	23	28	36	42

5.7.3 Mounting the Wave Generator (WG) to the Motor Shaft

The units are delivered with the Wave Generator adapted for the motor shaft. The hub of the Oldham coupling is secured on the motor shaft by means of a key or clamping element. Please observe the recommendations for the correct axial position of the Wave Generator inside the gearbox.

The axial attachment of the hub must withstand the axial forces acting on the Wave Generator. When mounted correctly, the motor shaft should extend at least 2/3 of the entire hub length, thereby ensuring reliable transmission of the motor torque.
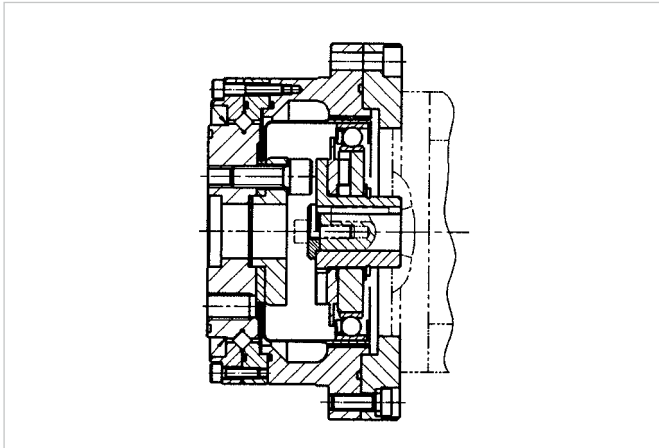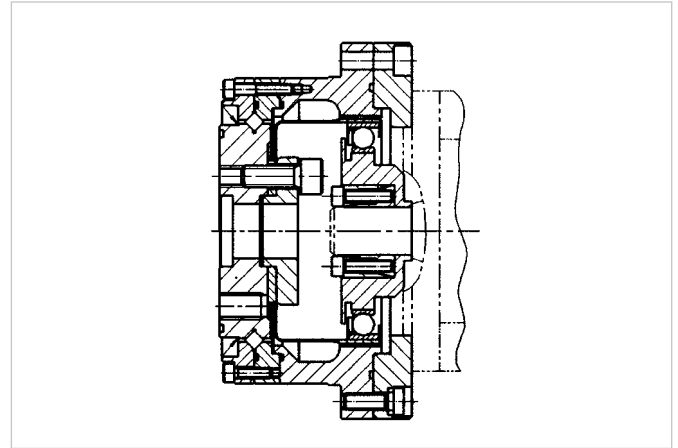
Illustration 48.1   Units with Keyway

Illustration 48.2   Units with Clamping Element

For stepping motor operation and for large motor shaft diameters the use of a solid Wave Generator is recommended. Illustration 48.1 shows the standard version with Oldham coupling and keyway. Illustration 48.2 shows a solid Wave Generator without Oldham coupling. The Wave Generator is attached directly to the motor shaft by means of a clamping element.

5.7.4 Check before Assembly of the Wave Generator (WG)

- 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 WG is lubricated in accordance with illustration 41.2. When the gear is oil lubricated, fill in the prescribed oil quantity.

5.7.5 Assembly Control

Very rarely, an eccentric tooth mesh, called dedoidal, may occur.
The correct assembly can be checked as follow:

- 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 49.1

Right

Wrong
(dedoidal)
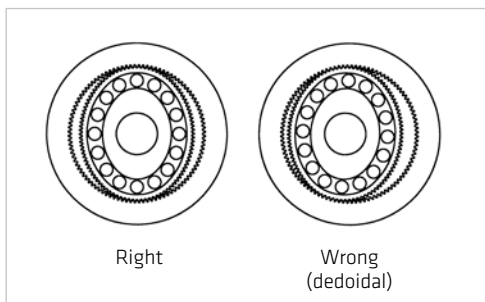
5.7.6 Assembly of the Output Flange

Illustration 50.1
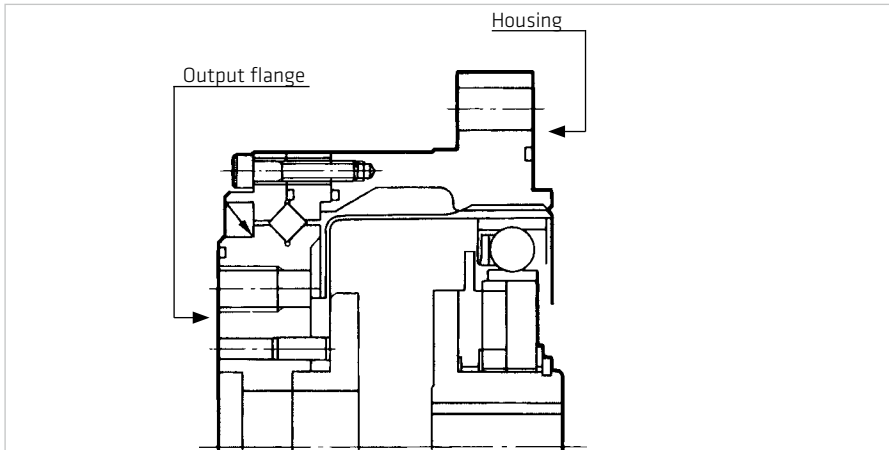
Table 50.2

Size		14	17	20	25	32	40
Number of Bolts		6	6	8	8	8	8
Bolt Size		M4	M5	M6	M8	M10	M10
Bolt pitch diameter	[mm]	23	27	32	42	55	68
Tightening Torque	[Nm]	5.4	10.8	18.4	45	89	89
Torque transmitting capacity*	[Nm]	58	109	245	580	1220	1510

5.7.7 Assembly of the Housing

Table 50.3

Size		14	17	20	25	32	40
Number of Bolts		8	8	8	10	12	10
Bolt Size		M4	M4	M5	M5	M6	M8
Bolt pitch diameter	[mm]	65	71	82	96	125	144
Tightening Torque	[Nm]	4.5	4.5	9	9	15.3	37
Torque transmitting capacity*	[Nm]	182	196	365	538	1200	2100

* Friction coefficient μ = 0.15; 12.9 quality screws

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.
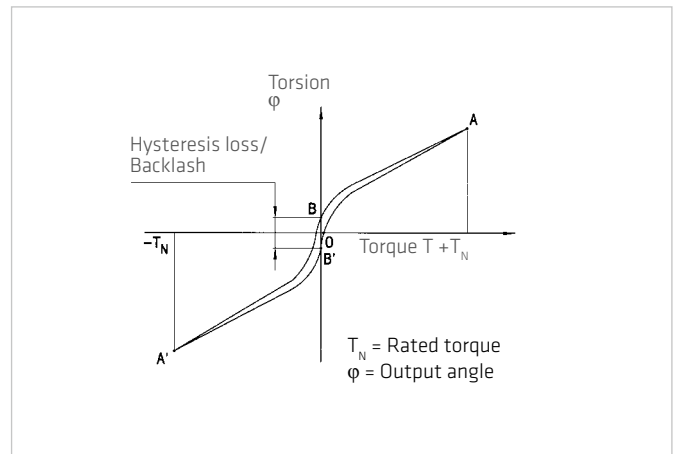
Brake holding torque T_{BR} [Nm]

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

Brake opening time t_O [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) $L_{L\text{-}L}$ [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.
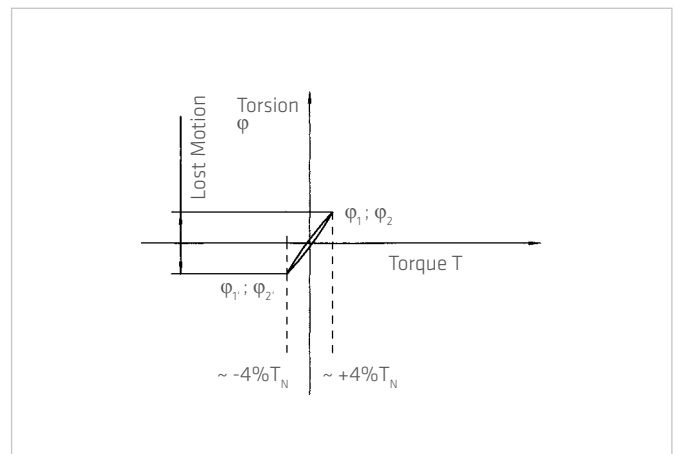
Maximum DC bus voltage $U_{DC\,(max)}$ [VDC]

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 [kgm^2]

Mass moment of inertia at motor side.

Moment of inertia J_{in} [kgm^2]

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

Moment of inertia J_{out} [kgm^2]

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.
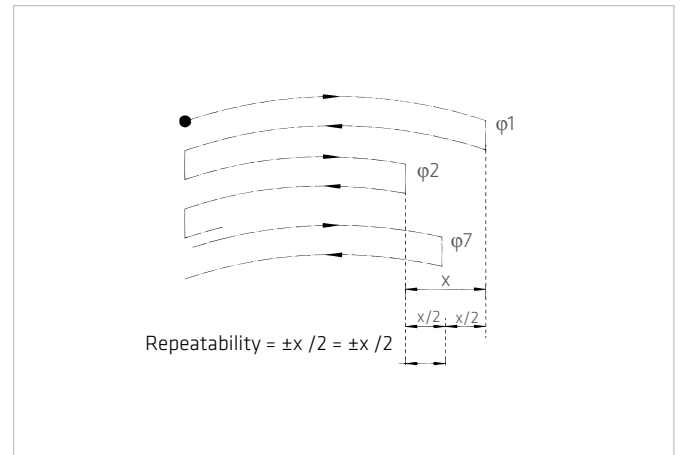
Resistance (L-L, 20° C) R_{L-L} [Ω]

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}]
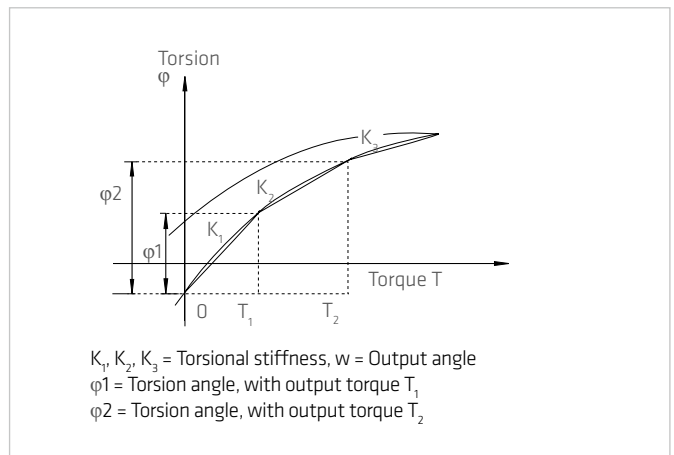
Quotient of stall torque and stall current.

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
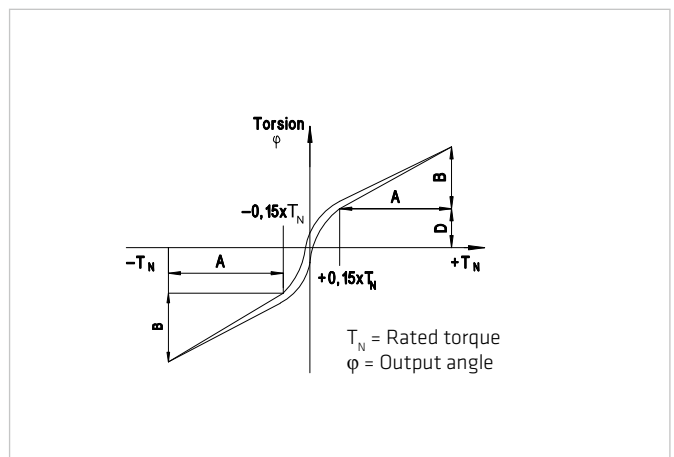
Transmission accuracy [arcmin]

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.
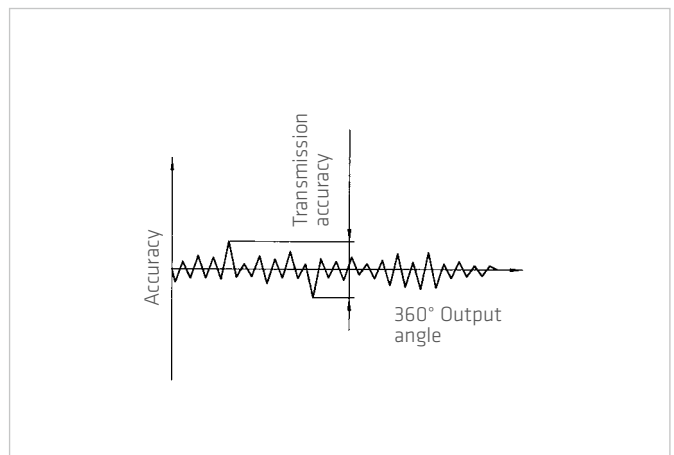
Weight m [kg]

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.