Engineering Data
PMG-M-S Gearboxes

Harmonic Drive AG

...just move it!

...just move it!

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:

Harmonic Drive AG
Marketing and Communications
Hoenbergstraße 14
65555 Limburg / Lahn
Germany
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 2006/42/EG. 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.

Small, economical gearbox

PMG Series Gearboxes are available in four sizes with gear ratios of 50, 72, 80, 88, 100 and 110:1 offering repeatable peak torques from 0.3 to 14.7 Nm.

The PMG Series is available in two versions: the PMG-M Gearbox with input hub for motor adaptation and the PMG-S Gearbox with input shaft. Both variants come with an output shaft.

If required, the Gearboxes can be tailored to your application and can be easily mounted direct to standard servo motors. Zero backlash means short cycle times and high accuracy.

3.2 Ordering Code

Table 9.1

Series	Size	Ratio [1]						Version	Special design
PMG	5A	50		80		100		M	According to customer requirements
	8A	50	72			100			
	11A	50	72			100		S	
	14A	50	72		88	100	110		
Ordering code									
PMG -	**8A** -	**100**			-	**M**	-	**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**
M	Close coupled model for motor adaptation
S	With input shaft

3.3 Technical Data

3.3.1 Generaly Technical Data

Table 10.1

	Unit	PMG-5A-M			PMG-8A-M		
Ratio	i [ ]	50	80	100	50	72	100
Repeatable peak toque	T_R [Nm]	0.3	0.45	0.55	1.9	2.4	2.7
Average torque	T_A [Nm]	0.3	0.45	0.55	1.9	2.3	2.7
Rated torque	T_N [Nm]	0.2	0.3	0.3	1.5	2.0	2.0
Momentary peak torque	T_M [Nm]	0.4	0.6	0.7	2.5	3.1	3.8
Maximum input speed (Grease lubrication)	$n_{in (max)}$ [rpm]	10000			6000		
Average input speed (Grease lubrication)	$n_{av (max)}$ [rpm]	4900			3500		
Moment of inertia	J_{in} [x10^{-8} kgm^2]	2.5			30		
Weight	m [kg]	0.030			0.120		

Table 10.2

	Unit	PMG-5A-S			PMG-8A-S		
Ratio	i [ ]	50	80	100	50	72	100
Repeatable peak toque	T_R [Nm]	0.3	0.45	0.55	1.9	2.4	2.7
Average torque	T_A [Nm]	0.3	0.45	0.55	1.9	2.3	2.7
Rated torque	T_N [Nm]	0.2	0.3	0.3	1.5	2.0	2.0
Momentary peak torque	T_M [Nm]	0.4	0.6	0.7	2.5	3.1	3.8
Maximum input speed (Grease lubrication)	$n_{in (max)}$ [rpm]	10000			6000		
Average input speed (Grease lubrication)	$n_{av (max)}$ [rpm]	4900			3500		
Moment of inertia	J_{in} [x10^{-8} kgm^2]	2.5			30		
Weight	m [kg]	0.031			0.125		

3.3.2 Dimensions

Illustration 11.1   PMG-5A-M   [mm]

Illustration 11.2   PMG-8A-M   [mm]
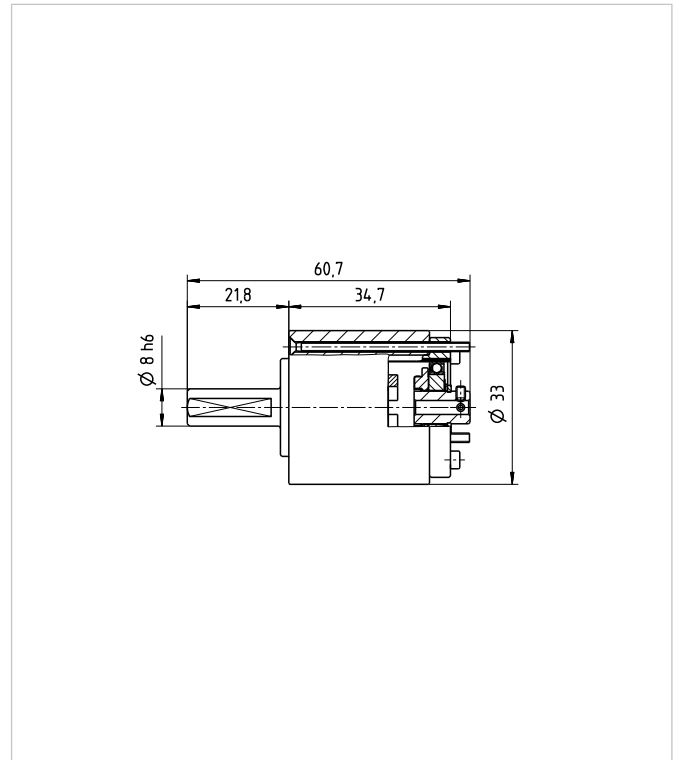
Illustration 11.3   PMG-5A-S   [mm]

Illustration 11.4   PMG-8A-S   [mm]
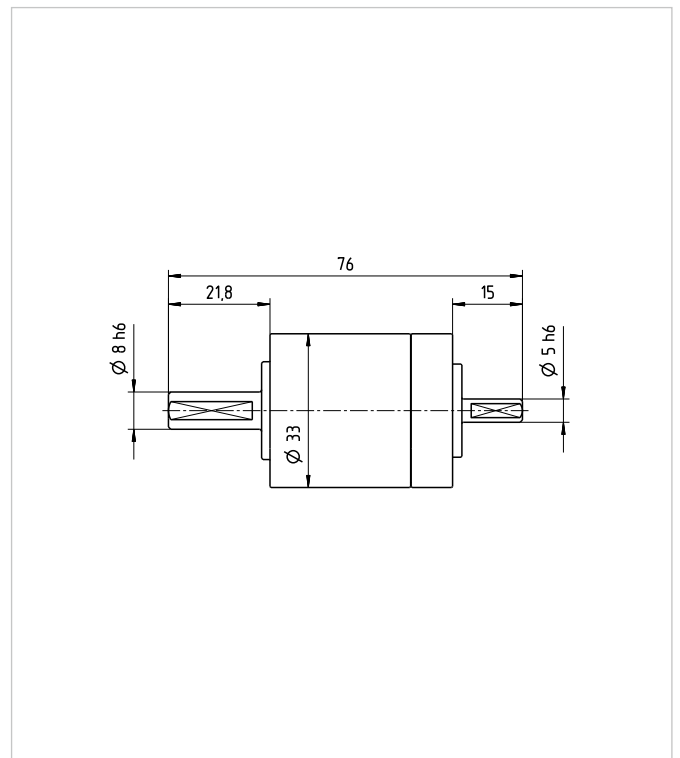
Table 12.1

	Unit	PMG-11A-M			PMG-14A-M				
Ratio	i [ ]	50	72	100	50	72	88	100	110
Repeatable peak toque	T_R [Nm]	5.0	5.6	7.9	9.8	11.8	12.7	14.7	14.7
Average torque	T_A [Nm]	4.7	5.4	7.6	7.0	9.0	11	11	11
Rated torque	T_N [Nm]	2.5	4.0	4.0	5.4	7.8	7.8	7.8	7.8
Momentary peak torque	T_M [Nm]	6.8	8.8	10.8	14	16	18	20	20
Maximum input speed (Grease lubrication)	$n_{in (max)}$ [rpm]	5000			5000				
Average input speed (Grease lubrication)	$n_{av (max)}$ [rpm]	3500			3500				
Moment of inertia	J_{in} [x10^{-8} kgm²]	120			330				
Weight	m [kg]	0.25			0.42				

Table 12.2

	Unit	PMG-11A-S			PMG-14A-S				
Ratio	i [ ]	50	72	100	50	72	88	100	110
Repeatable peak toque	T_R [Nm]	5.0	5.6	7.9	9.8	11.8	12.7	14.7	14.7
Average torque	T_A [Nm]	4.7	5.4	7.6	7.0	9.0	11	11	11
Rated torque	T_N [Nm]	2.5	4.0	4.0	5.4	7.8	7.8	7.8	7.8
Momentary peak torque	T_M [Nm]	6.8	8.8	10.8	14	16	18	20	20
Maximum input speed (Grease lubrication)	$n_{in (max)}$ [rpm]	5000			5000				
Average input speed (Grease lubrication)	$n_{av (max)}$ [rpm]	3500			3500				
Moment of inertia	J_{in} [x10^{-8} kgm²]	140			340				
Weight	m [kg]	0.27			0.495				

Illustration 13.1   PMG-11A-M   [mm]
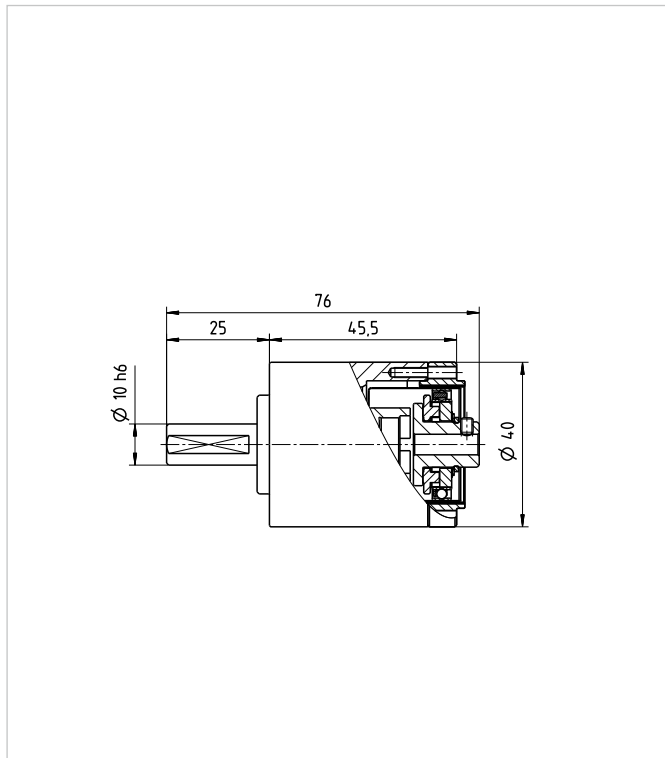
Illustration 13.2   PMG-14A-M   [mm]
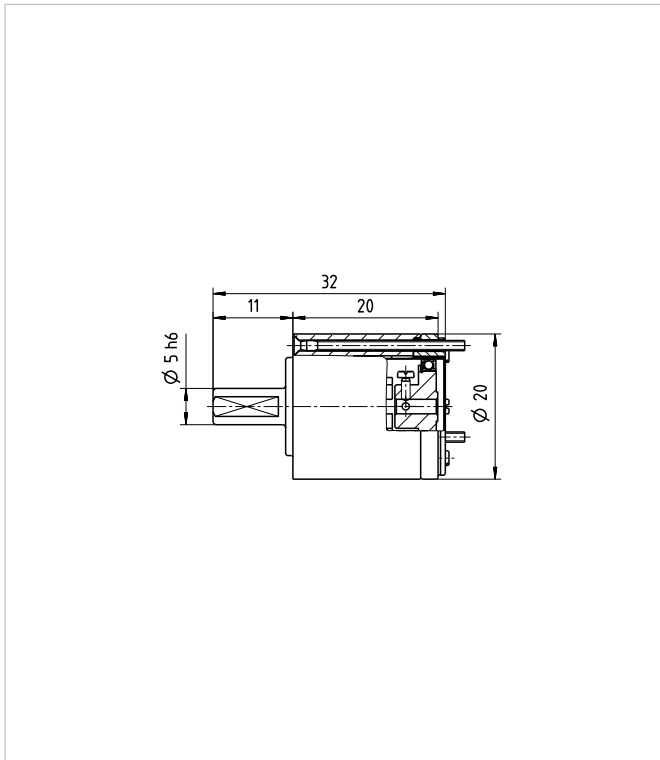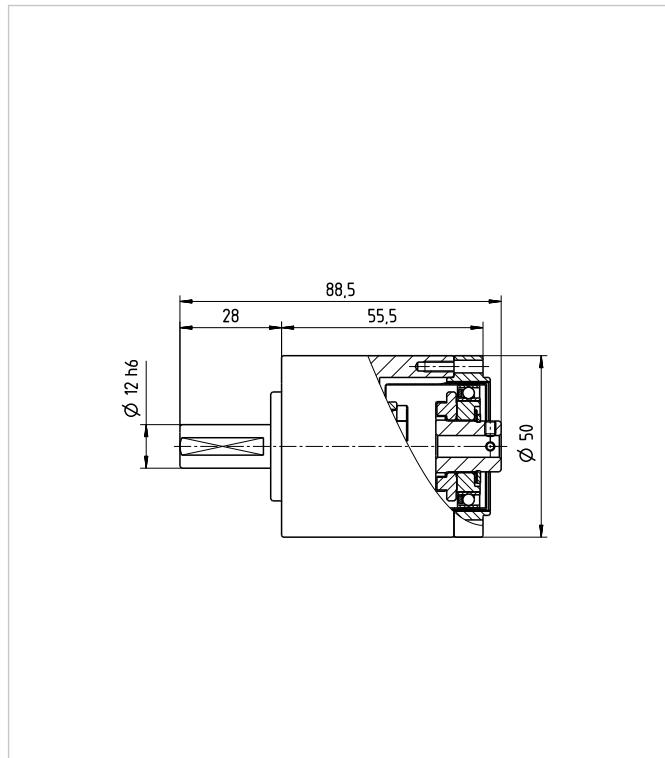

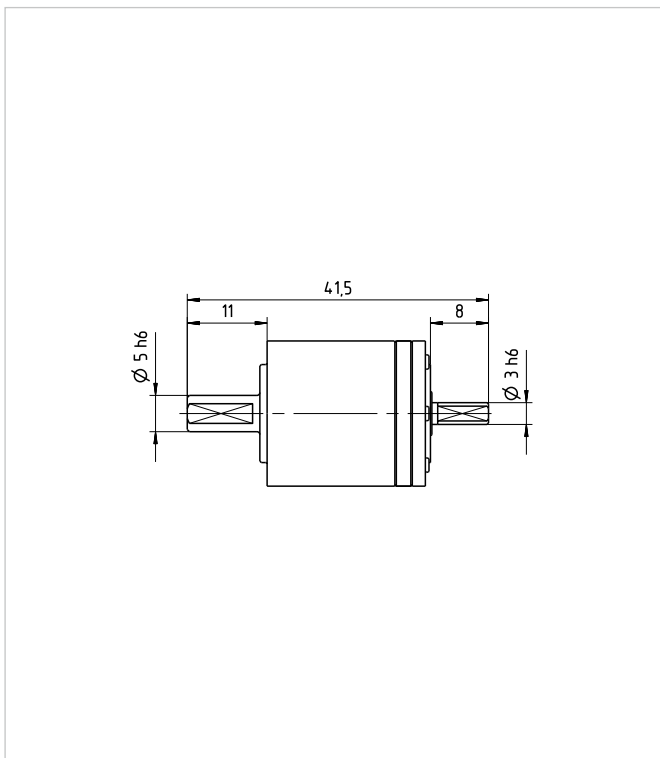Illustration 13.3   PMG-11A-S   [mm]
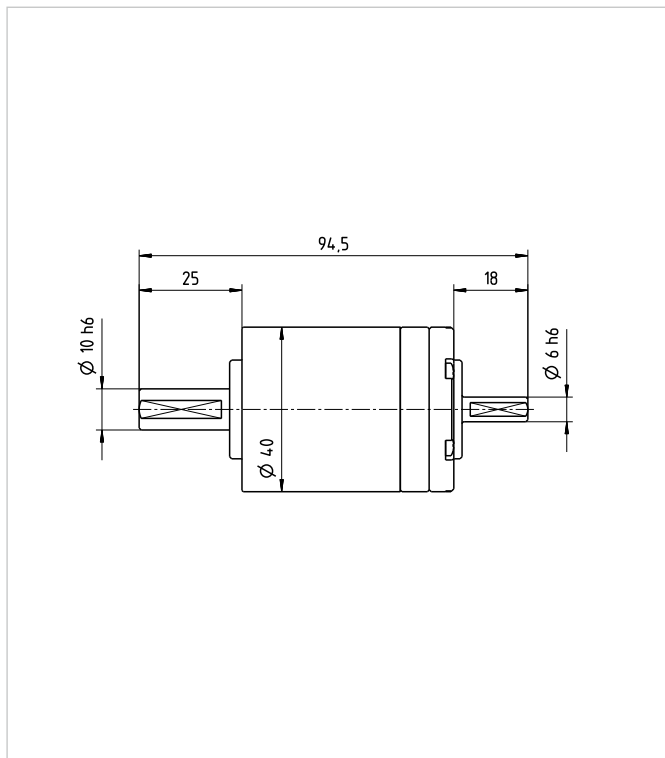
Illustration 13.4   PMG-14A-S   [mm]

QUICKLINK
www.harmonicdrive.de/CAD2090
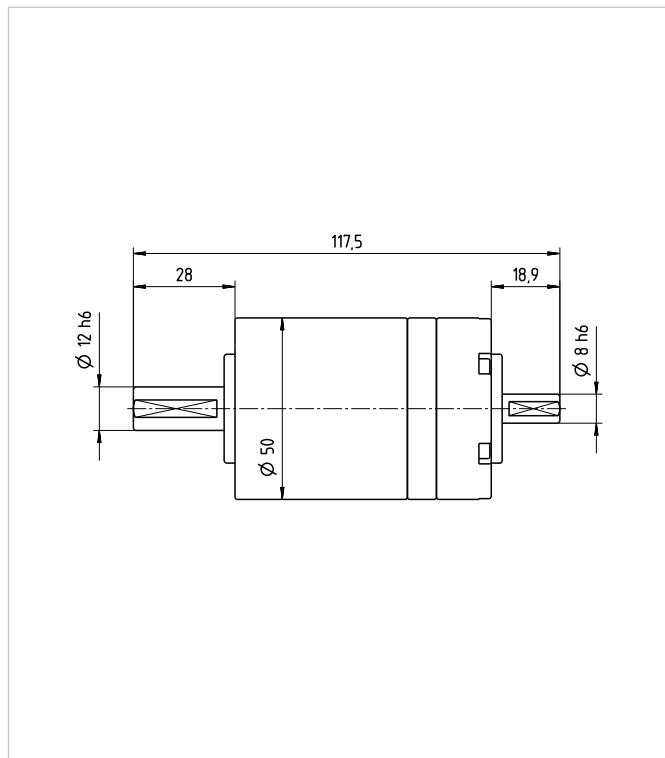
3.3.3 Accuracy

Table 14.1 [arcmin]

Size	5	8	11	14
Transmission accuracy	<4.5	<3	<2.0	<2.0
Lost Motion	<4	<1.0	<1.0	<1.0
Repeatability	<± 1.5	<± 1.0	<± 1.0	<± 1.0

3.3.4 Torsional Stiffness

Table 14.2

Size		5	8	11	14
T_1 [Nm]		0.05	0.3	0.8	1.9
T_2 [Nm]		0.19	1.5	3.4	6.8
i = 50	K_2 [Nm/rad]	55	389	1160	2250
	K_1 [Nm/rad]	24	246	622	1320
i > 50	K_3 [Nm/rad]	100	690	1400	4270
	K_2 [Nm/rad]	60	500	1320	3300
	K_1 [Nm/rad]	30	380	770	1710

3.3.5 Bearings

The PMG gearboxes 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 14.3 lists ratings and important dimensions for the output bearings.

Table 14.3 [N]

Size		Unit	5	8	11	14
Output bearing	Permissible radial force [1]	F_r [N]	59	196	245	392
	Permissible axial load	F_a [N]	29	98	196	392
	Static load rating	C_0 [N]	282	1273	2370	3970
	Dynamic load rating	C_r [N]	734	2695	5237	6327
	Pitch circle ø	d_p [mm]	8	16	20	23.5
Input bearing	Permissible radial force [1]	F_r [N]	8	10	20	29
	Permissible axial load	F_a [N]	5	5	10	10

[1] The radial load is based on a force applied at the midpoint of the shaft extension.

Output Shaft Tolerances

Illustration 15.1
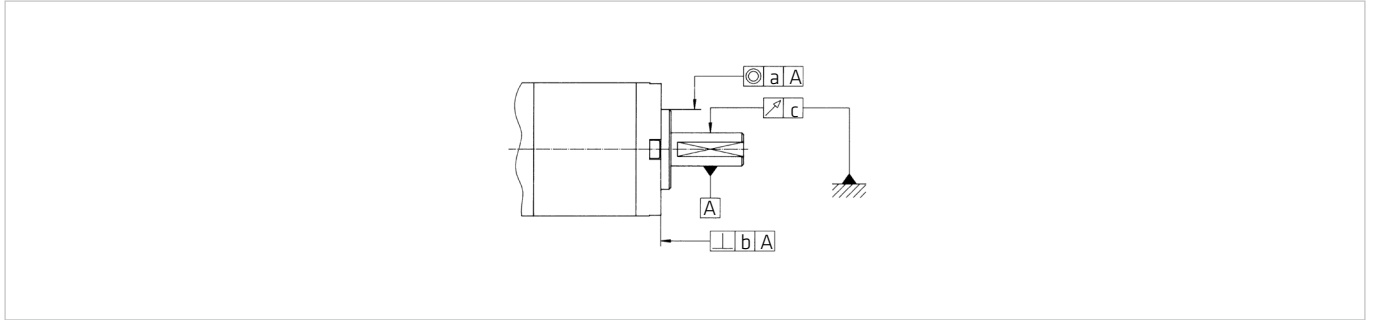
Table 15.2   [mm]

Size	5	8	11	14
a	0.04	0.04	0.04	0.04
b	0.04	0.04	0.04	0.04
c	0.02	0.02	0.02	0.02

3.3.6 Materials Used

Housing:Cast iron, chemically nickel plated and aluminium, anodised.
Adapter flange, if supplied by Harmonic Drive AG: High-tensile aluminium or steel.

Surfaces:
Screws: Corrosion protected (Delta-tone) or stainless steel.
Shafts: Stainless 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
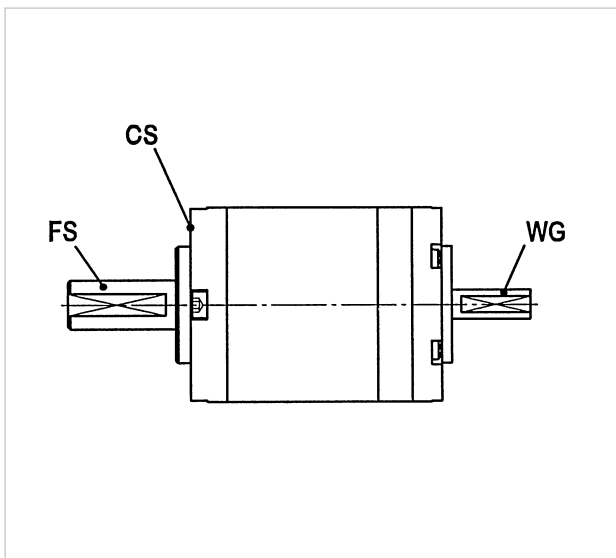
The values for ratios of Harmonic Drive® gears refer to the standard input and output arrangement (example 1 in the table below). Other arrangements are possible, and also shown in the table.

Ratio

1)
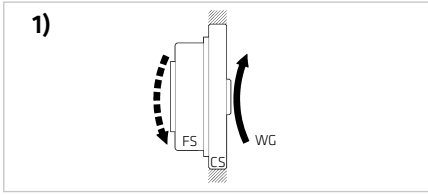
Reduction gearing
CS	Fixed
WG	Input
FS	Output

Equation 17.1

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

Input and output rotate in opposite directions.

2)
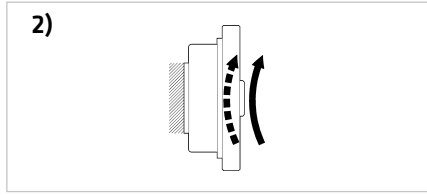
Reduction gearing
FS	Fixed
WG	Input
CS	Output

Equation 17.2

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

Input and output rotate in same direction.

3)
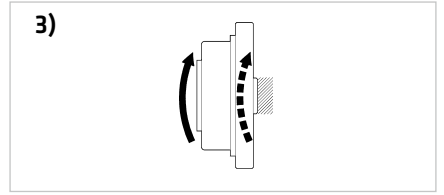
Reduction gearing
WG	Fixed
FS	Input
CS	Output

Equation 17.3

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

Input and output rotate in same direction.

4)
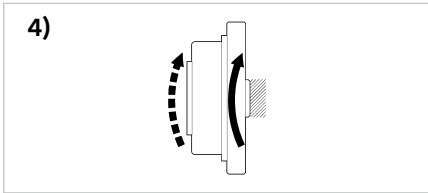
Speed increaser gearing
WG	Fixed
CS	Input
FS	Output

Equation 17.4

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

Input and output rotate in same direction.

5)
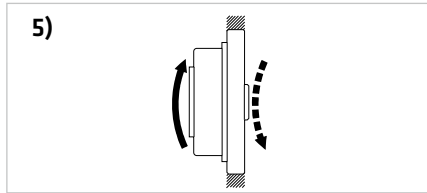
Speed increaser gearing
CS	Fixed
FS	Input
WG	Output

Equation 17.5

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

Input and output rotate in opposite directions.

6)
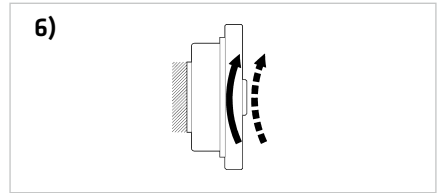
Speed increaser gearing
FS	Fixed
CS	Input
WG	Output

Equation 17.6

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

Input and output rotate in same direction.

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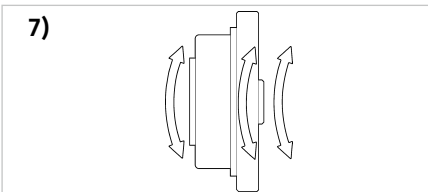
Differential gear
WG	Control input
CS	Main drive input
FS	Main drive output

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.

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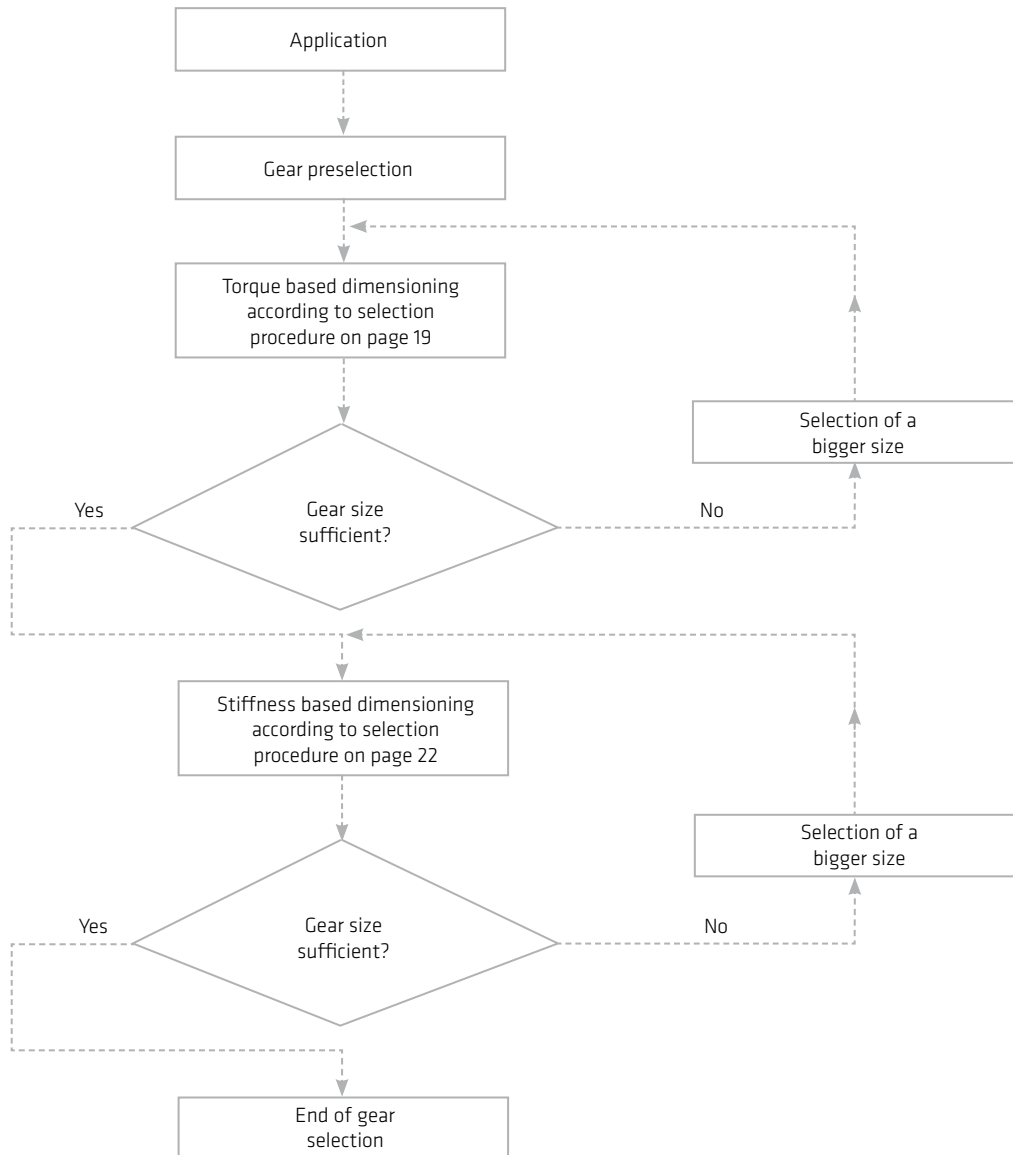
4.1.1 Torque Based Dimensioning

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
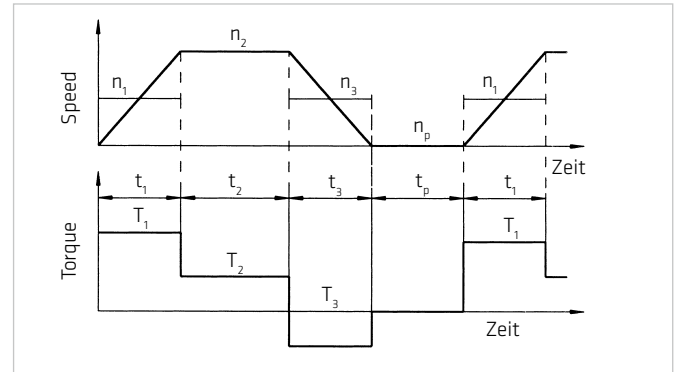
Equation 19.2

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

Equation 19.7

Permissible average input speed
$$n_{in\,av} \leq \text{Limit for average input speed}$$
(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

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

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

$T_1 =$	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}

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

T_{av} = 319 Nm ≤ T_A = 451 Nm

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

Calculation of the average
output speed

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

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:

$$L_{50} = \frac{35000\ h \cdot 2000\ rpm}{1440\ rpm} \cdot \left(\frac{294\ Nm}{319\ Nm}\right)^3$$

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

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

fn = Resonance frequency [Hz]
K1 = Gear torsional stiffness K1 [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 nn 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 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:
$n_n = 30 * 30 = 900$ [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 = Torque [Nm]
K = Stiffness [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

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

$$\varphi = 7.15 \cdot 10^{-4} \text{ rad}$$
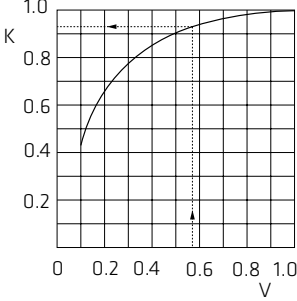
$$\varphi = 2.5 \text{ arc min}$$

Equation 24.4

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

4.3 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.

4.3.1 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: Grease
The efficiency may be determined using the efficiency graphs.	From matching chart η = 78 %
Calculate the torque factor V. $$V = \frac{T_{av}}{T_N} \quad \text{[Equation 25.2]}$$ with: T_{av} = Average torque T_N = Rated torque at rated speed	T_{av} = 19.6 Nm T_N = 34.0 Nm $$V = \frac{19.6\ Nm}{34.0\ Nm} = 0.57$$
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

4.3.2 Efficiency Tables

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 page 27.
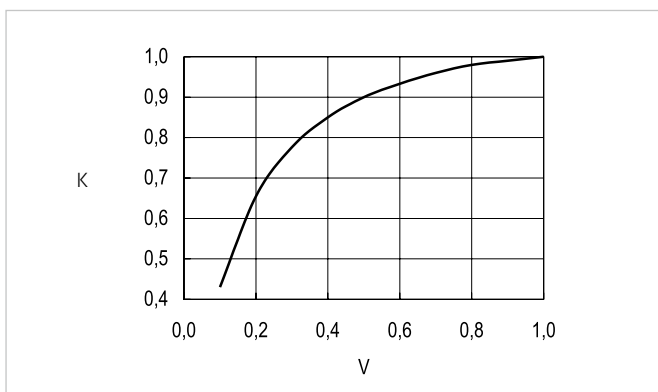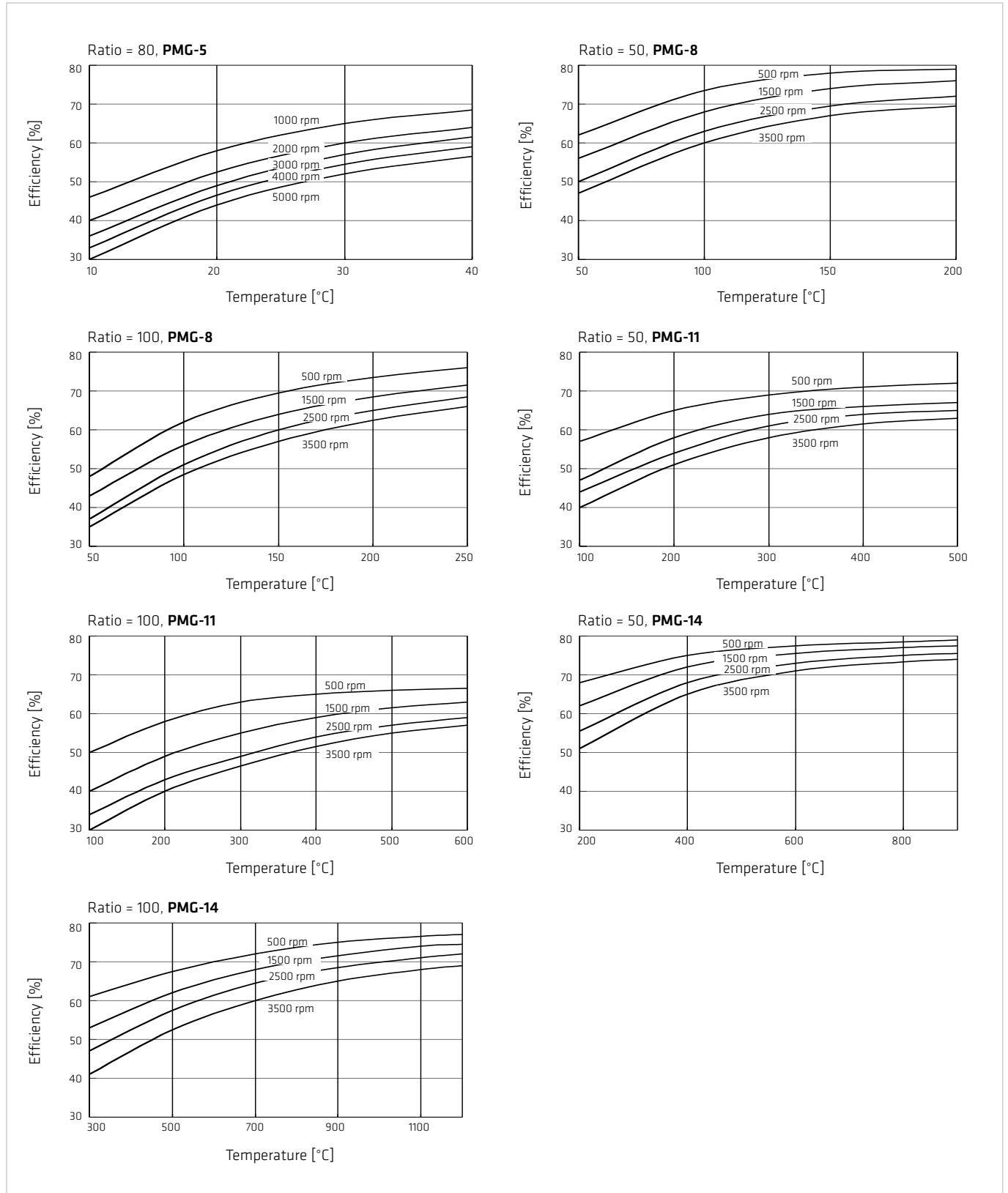
Efficiency for grease lubrication at rated torque

Illustration 26.1

4.4 No Load 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 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.

4.4.1 No Load Running Torque

Table 27.1   [Ncm]

Ratio	Size			
	5	8	11	14
50	0.4	0.8	1.6	2.3
72, 80, 88	0.3	0.7	1.3	1.9
100, 110	0.3	0.6	1.1	1.6

4.4.2 No Load Back Driving Torque

Table 27.2   [Nm]

Ratio	Size			
	5	8	11	14
50	0.18	0.5	0.9	1.3
72, 80, 88	0.2	0.6	1.0	1.6
100, 110	0.3	0.7	1.1	1.8

4.5 Output Bearing Operating Life

The PMG Gearboxes are fitted as standard with a high capacity output bearing (see section 3.3.5). Please contact us to estimate the operating life for the output bearing. The PMG Gearboxes are fitted as standard with a high capacity output bearing (see section 3.3.5). Please contact us to estimate the operating life for the output bearing.

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.

Caution!

The Harmonic Drive® high performance 4BNo.2 grease becomes relatively thin 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 28.1

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												
SK-1A	–			Standard											
SK-2	Standard			–											
4BNo.2	–		For heavy duty operation*												

Table 28.2

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

Table 29.1

| 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 30.1 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 30.1

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.

4.6.2 Oil Lubrication

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

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.
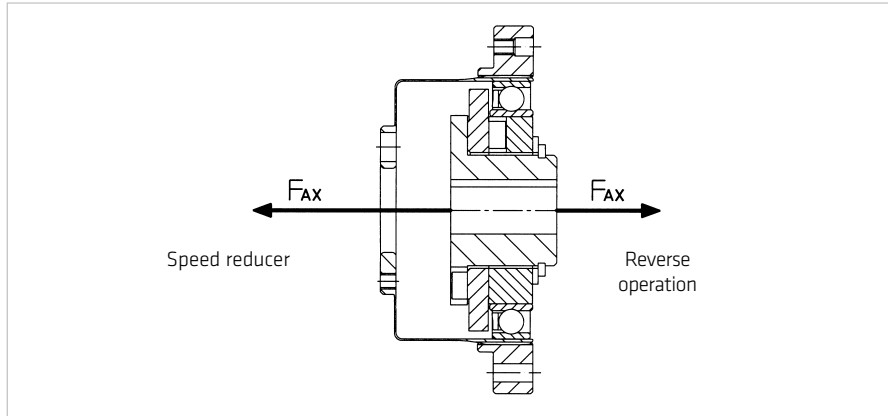
Illustration 31.1

Table 31.2

Ratio		
30	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 32°$	[Equation 31.3]
50	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 30° + 2\mu PF$	[Equation 31.4]
80...160	$F_{AX} = 2 \cdot \dfrac{T}{D} \cdot \mu \cdot \tan 20° + 2\mu PF$	[Equation 31.5]

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 = 300 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 31.6

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 PMG-M

In order for the full features of Harmonic Drive® Units to be exploited fully, it is essential that the tolerances according to table 33.2 are observed for the input assembly.
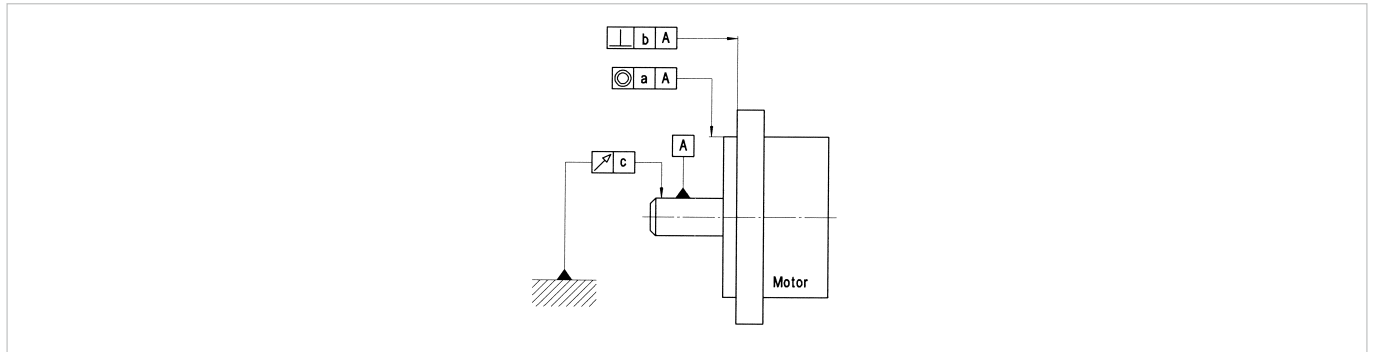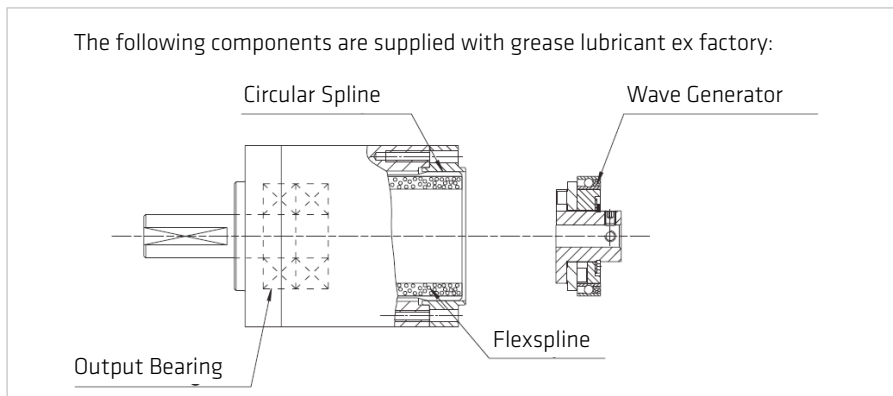
Illustration 33.1

Table 33.2   [mm]

Size	5	8	11	14
a	0.015	0.025	0.030	0.030
b	0.015	0.025	0.030	0.030
c	0.010	0.015	0.015	0.015

5.5 Grease Lubrication

Gearboxes are supplied with standard grease lubricant. Illustration 33.3 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 33.3

The following components are supplied with grease lubricant ex factory:

Circular Spline   Wave Generator

Output Bearing   Flexspline

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 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.
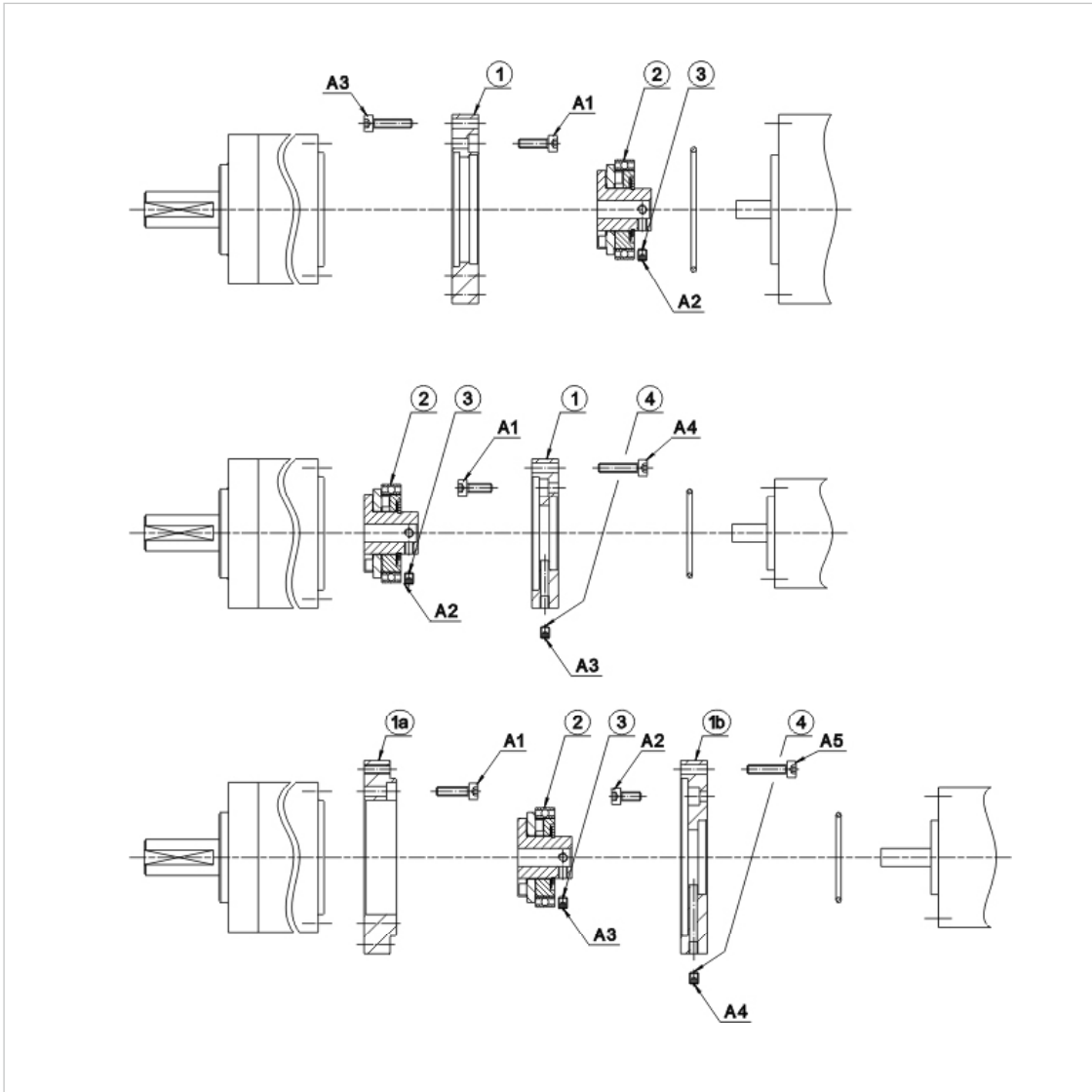
5.7 Assembly

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

Caution:
Contrary to the illustration on Illustration 35,1 the Wave Generator (2) of size 5 gearboxes
is mounted with grub screws on the left. Please consider the confirmation drawing.

Illustration 35.1

5.7.1 Motor Assembly PMG-M

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.

5.7.2 Manufacturing of the Adaptor Flange

For the manufacturing of the adaptor flange we recommend the dimensions and tolerances given in illustration 36.1 and table 36.2. To achieve the given value for concentricity and run-out we recommend that the motor- and gear-side centerings, see illustration 36.1, surface B and C, are manufactured at a single set-up. All bore holes and thread holes must be chamfered.

Illustration 36.1
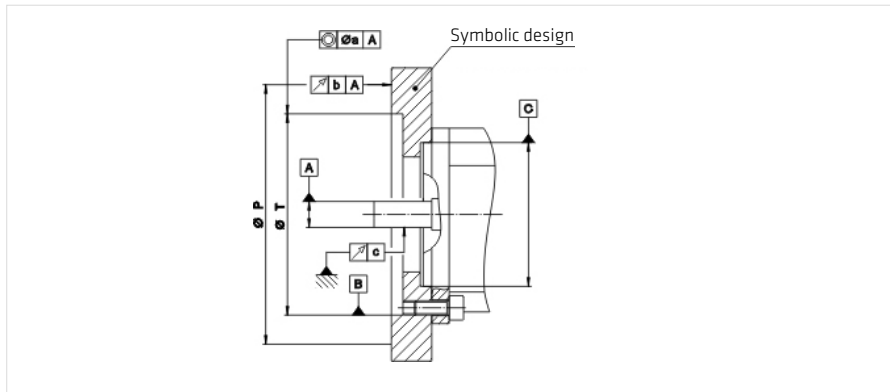
Table 36.2   [mm]

Size	5	8	11	14
Concentricity ⌀ a	0.005	0.015 (0.006)	0.015 (0.007)	0.030 (0.016)
Runout b	0.008	0.010	0.011	0.011
Runout c	0.010	0.015	0.015	0.015
⌀ P	16.4	29.5	35	44

() The values in brackets are the recommended tolerances for gears with a Solid Wave Generator.

5.7.3 Wave Generator Components PMG-M

Illustration 37.1 shows a standard Wave Generator with Oldham Coupling.

Illustration 37.1
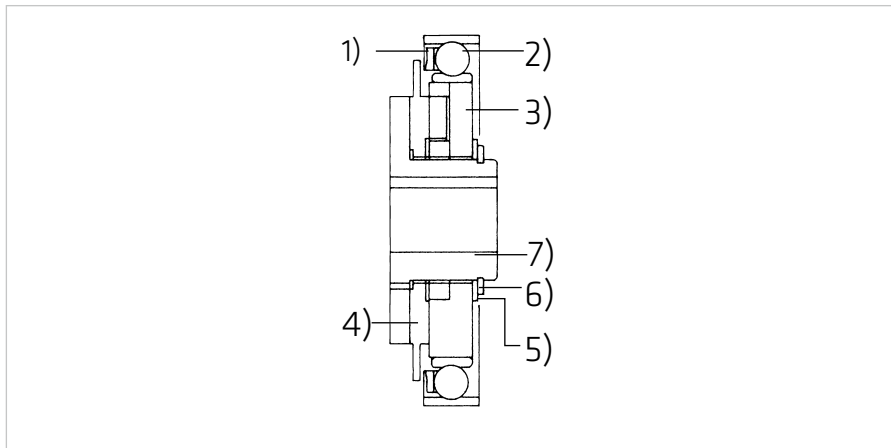
1) Ball Separator
2) Wave Generator bearing
3) Wave Generator plug
4) Insert
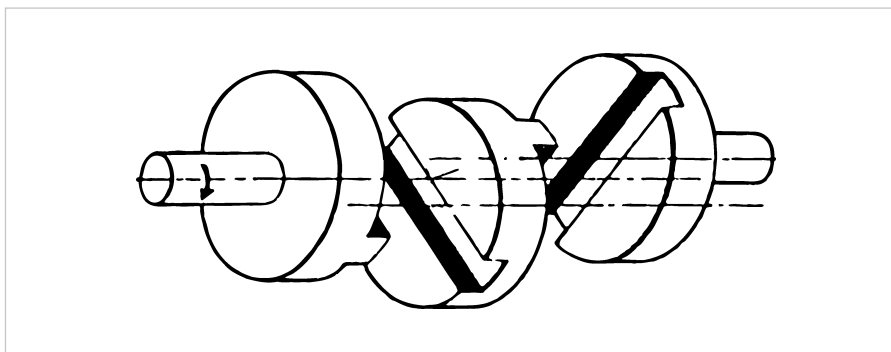5) Thrust washers
6) Snap ring
7) Wave Generator hub

Wave Generator Modifications

PGM-M units are provided with an Oldham coupling to compensate for eccentricity of the input shaft (see illustration 37.2).

Principle of an Oldham coupling

Illustration 37.2

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

Illustration 35.1 shows some possibilities how to assemble the gearboxes to the motor. If the designs of the components differ from those shown in illustration 35.1, please follow the instructons as appropriate.

Removal of the Protection Cap
If a protection cap is mounted, please remove it

Assembly of the Adaptor Flange
Connect the adaptor flange(s) (1) according to illustration 35.1.

Grease Quantity Check
Please refer to section 5.7 for more information

- The axial position of the Wave Generator in the gearbox is critical for the correct operation of the unit. Please check the correct position of the Wave Generator against the confirmation drawing.

- Push the greased Wave Generator (2) onto the motor shaft according to the assembly dimension given in the confirmation drawing. If there is no assembly value given, the Wave Generator must be moved until it reaches the shaft collar.

- Fix the Wave Generator (2) with the set screw (3). Set screw tightening torques are listed in table 39.5

- Eventually seal the flange (1) with the set screw (4). Please consider section 5.6. If a glued shaft-hub connection is used, please pay attention to the information given in section 5.6.

Assembly of the motor/adaptor flange sub-assembly to the Gearbox
It is essential that the components are carefully aligned during the assembly. The teeth of the Flexspline and Circular Spline must mesh symmetrically for proper function.
Alternatively, the motor assembly can be carried out while the motor shaft is rotating slowly (n <10 rpm). This procedure simplifies the assembly. The assembly must be performed generally without using undue force.

Tighten the screws crosswise in three steps.

5.7.5 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. When the gear is oil lubricated, fill in the prescribed oil quantity.

5.7.6 Assembly of the Wave Generator (WG) into the Flexspline (FS)

When the Wave Generator is assembled into the Flexspline please consider that the parts must not be tilt during assembly. By parallel assemby 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.

5.7.7 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.
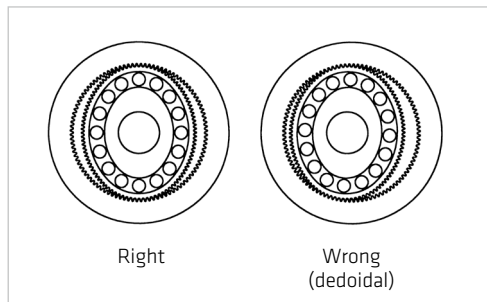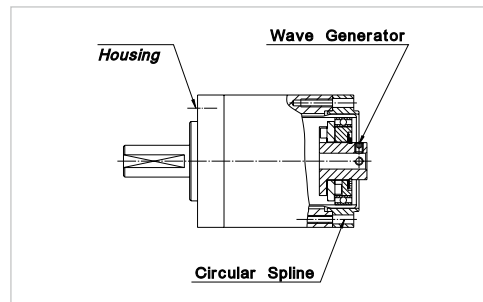
Illustration 39.1

Right   Wrong (dedoidal)

Illustration 39.2

5.7.8 Assembly of the Motor Flange PMG-M

Table 39.3   [Nm]

Size	5	8	11	14
Bolt Size	M1.4	M2	M2.5	M3
Tightening Torque	0.21	0.65	1.3	2.3

5.7.9 Assembly of the Output Flange

Table 39.4

Size	5	8	11	14
Bolt Size	M2	M3	M4	M5
Tightening Torque	0.65	2.3	5.3	10.5

5.7.10 Assembly of the Input Shaft PMG-M

Table 39.5

Size	5	8	11	14
Size Set screw	M1.2	M2	M3	M3
Tightening Torque	0.06	0.38	1.34	1.34

The tables are valid for completely degreased mating surfaces (coefficient of friction $\mu_k = 0.15$) and 12.9 quality screws with metric thread according to DIN 13 Part 13 and head dimensions of screws according to ISO 4762 (set screws to ISO 4026), non-treated, oiled, with $\mu_{tot} = 0.12$.

6. Glossary

6.1 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 A where the value B-B is defined as the backlash or hysteresis.
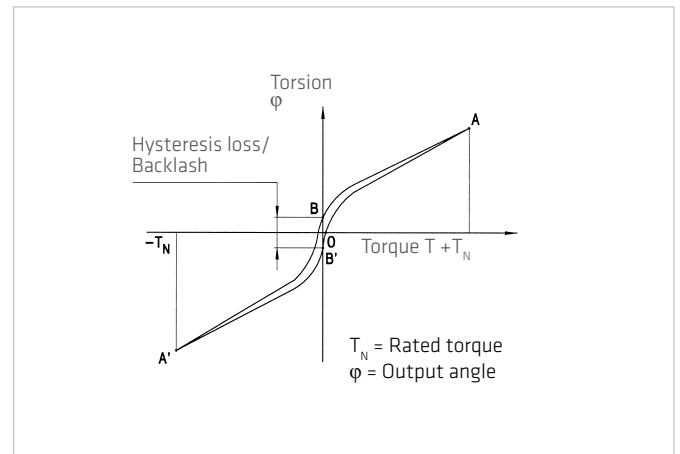
Brake closing time t_C [ms]

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_H [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.

Collision 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 tom a minimum and under no circumstances should the collision torque occur during the normal operating cycle.

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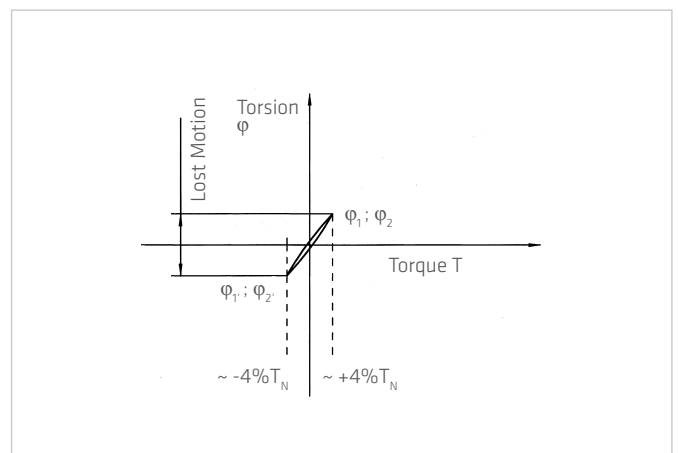
Maximum DC bus voltage $U_{DC (max)}$ [VDC]

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 diameter of the axial hollow shaft.

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

Maximum allowed input speed for gearing with grease lubrication.

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

Maximum allowed 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 rated speed is greater than the permissible continuous operation calculated in the 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 parameterized 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 average torque is within the permissible continuous operation calculated in the 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 tom a minimum and under no circumstances should the momentary peak 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 load.

Pitch circle diameter d_p [mm]

Pitch circle diameter of the output bearing.

Protetcion 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]

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

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], Mechanic

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® transmission: The standard version of the wave is generating the drive element, the output element of the flexspline and the circular Spline is fixed to the housing. Since the direction of rotation of the drive (Wave Generator) to output reverses (Flexspline), a negative ratio for results Calculations in which the direction of rotation must 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.

Repeatability = ±x /2 = ±x /2
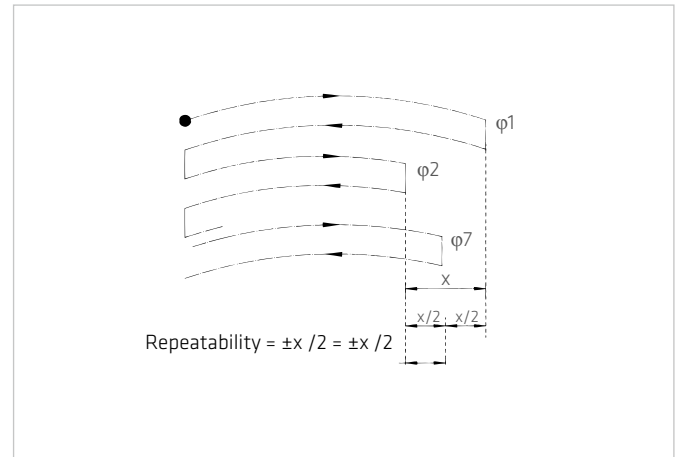
Repeatable peak torque T_R [Nm]

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 theiron 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]

The tilting angle of the output bearing at an applied moment load.

Torque constant (motor) k_{TM} [Nm/A$_{rms}$]
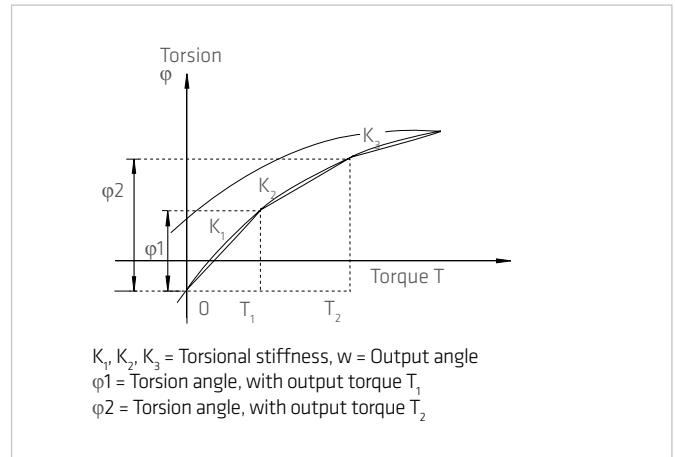Quotient of stall torque and stall current.

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 and the Wave Generator blocked. The torsional stiffness K$_3$ describes the stiffness above a defined reference torque where the stiffness is almost linear. Values below this torque can be requested or found on our web site.

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 Gesamtverdrehwinkels can be found in the secondary technical documentation.

K$_1$, K$_2$, K$_3$ = Torsional stiffness, w = Output angle
φ1 = Torsion angle, with output torque T$_1$
φ2 = 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
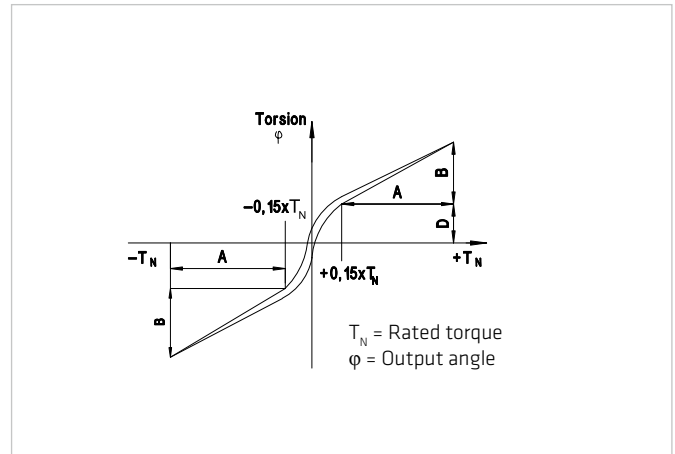
Transmission accuracy [arcmin]

The transmission accuracy of the gear represents a 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 theoretical and actual output rotation angle.
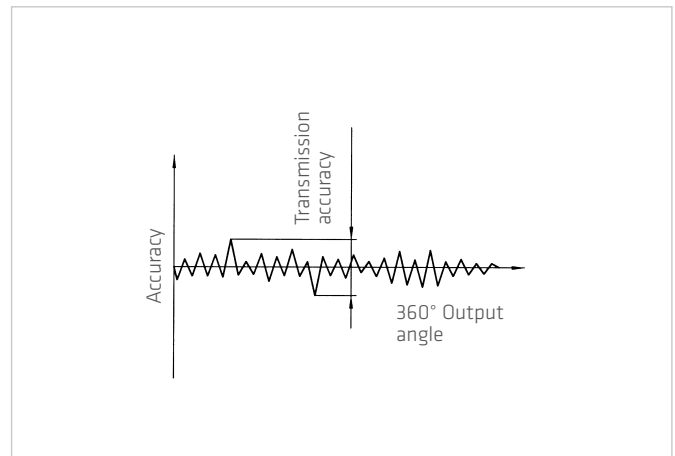
Weight m [kg]
The weight specified in the catalog is the net weight without packing and only applies to standard versions.

6.2 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.

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