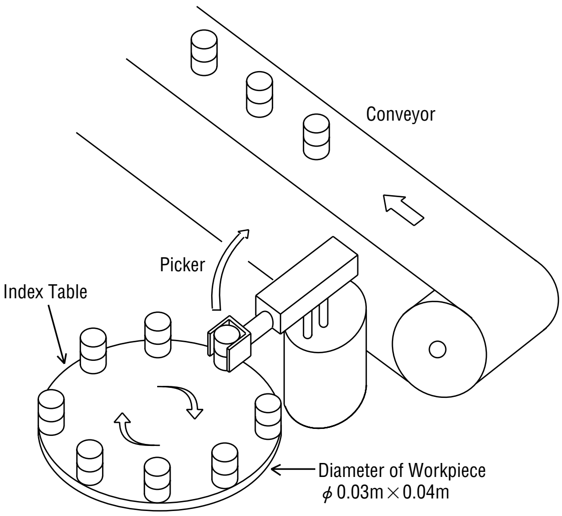
Advantages of Geared Stepping Motors

Speed reduction package have come into wide use with the general objectives of increasing torque and reducing speed. However, they are also used in combination with stepping motors requiring high positioning precision for the sake of higher resolution, lower vibration, high inertia drive, and downsizing.
Here we will explain the advantages of geared stepping motors comparing the case for selecting the motor alone and the case for selecting a geared type.

Selection Conditions

The drive section will be selected for an index table like that in the figure below.
Conditions

Index table diameter	0.2 m
Index table thickness	0.008 m
Index table material	Aluminum
Work diameter	0.03 m
Work thickness	0.04 m
Work material	Iron
Qty of work	8
Total moment of inertia	3.72×10^{-3} kg·m^2
Resolution	0.4˚ maximum
Positioning time	0.2 second maximum
Positioning angle	45˚



Selection example

This selection procedure calculates the minimum positioning time and calculates various parameters for two different conditions: when the motor alone is selected for the drive for the index table in the figure on the left and when a geared type motor is selected.
Therefore, this procedure has a different sequence in places from the selection procedure given below.

1. Drive inertia

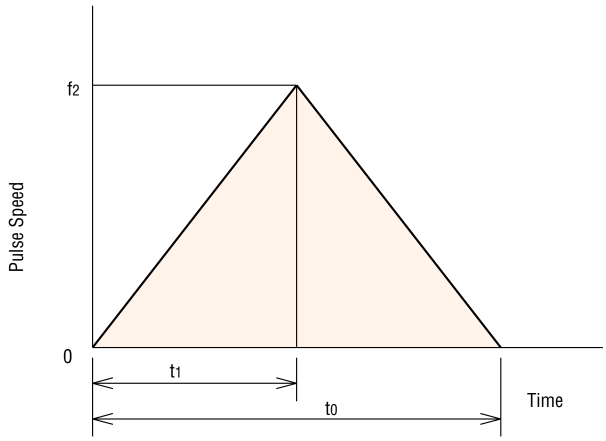
The ratio of the moment of inertia of the load converted for the motor output shaft and the moment of inertia of the rotor is called the inertia ratio and is expressed with the following equation.

$$\text{Inertia ratio} = \frac{\text{total moment of inertia}}{\text{moment of inertia of rotor} \times \text{gear ratio}^2}$$

If the inertia ratio is too large, this may affect the start up time and settling time due to overshoot and undershoot during starting and stopping. For the **RK** series, a maximum of 10 is one scale.
Therefore, when thinking about the motor alone, for this device the **RK5913AC** with a moment of inertia for its rotor of 4000×10^{-7} kg·m^2 is appropriate.
For a geared type, thinking of the **RK564AC-T7.2**, $(3.72\times10^{-3})/(175\times10^{-7}\times7.2^2)= 4.1$, which is an inertia ratio below 10.
Below, we calculate various parameters for both types.

2. Positioning time

We will compare the minimum positioning time using a motor alone and using a geared type. The drive pattern is triangular-wave drive like that shown in the figure and the acceleration/deceleration rate is 20 ms/kHz.



If the pulse velocity is f_2, the positioning time t_1, the operation pulse count A, and the acceleration rate Tr, then the following equation holds.

Acceleration/deceleration rate (Tr)

$$Tr = \frac{T_1\ [ms]}{f_2\ [kHz]} = 20\ [ms/kHz] \cdots\cdots (1)$$

$$A = t_1 \times f_2\ [pulses] \cdots\cdots (2)$$

$$t_0 = 2 \times t_1\ [ms] \cdots\cdots (3)$$

From Equations (1) and (2),

$$t_1 = \sqrt{20 \times A}\ (ms) \cdots\cdots (4)$$

●For motor alone:

Half step of 0.36°/step and operation pulse count A = 45/0.36 = 125
From Equation (4), t_1 = 50 [ms]. Therefore, the positioning time t_0 = 100 ms.

●For geared motor alone:

Full step of 0.1°/step and operation pulse count A = 45/0.1 = 450.
From Equation (4), t_1 = 95 [ms]. Therefore, the positioning time t_0 = 190 ms.

Selection results

The table below summarizes the results of these calculations.

●Comparison of operation conditions

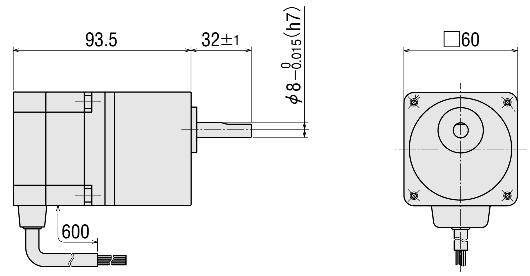
Package Model	**RK5913AC** (half step)	**RK564AC-T7.2** (full step)
Total moment of inertia	3.72×10^{-3} kg·m^2	
Operation pulse count	125 pulses	450 pulses
Operation pulse speed (r/min)	2500 Hz (150 r/min)	4700 Hz (78.3 r/min)
Acceleration/deceleration time	50 ms	95 ms
Positioning time	100 ms	190 ms
Required torque	2.59 N·m	0.81 N·m
Inertia ratio	9.3	4.1
Acceleration/deceleration rate	20 ms/kHz	20 ms/kHz

Advantages of geared types

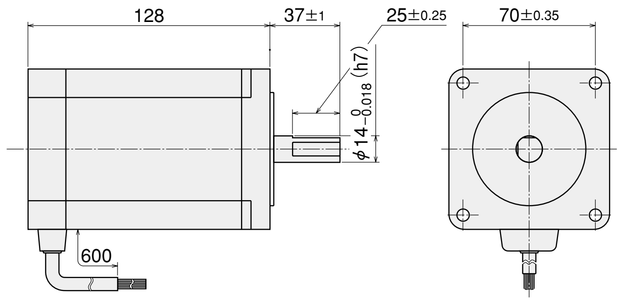
Using geared type motors provides the following advantages.

●Downsizing

This does not mean just increasing the torque by using a geared type motor. Rather, whereas the inertia that the motor itself can drive is 10 times the rotor inertia, the geared type can drive this inertia multiplied by the square of the speed reduction ratio. Therefore, for driving an inertial body such as in this case, selecting a geared type makes it possible to reduce the installation dimension from 85 mm → 60 mm square and the total length from 128 mm to 93.5 mm.



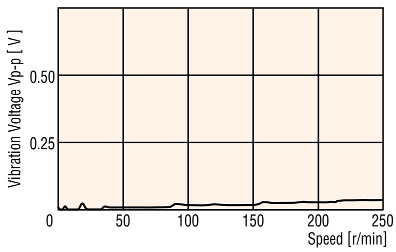
RK564AC-T7.2 Dimensions



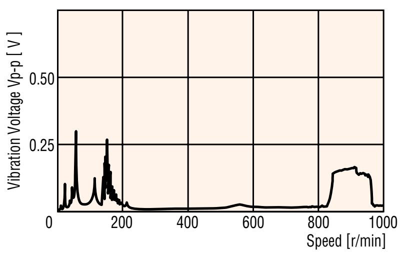
RK5913AC Dimensions

●Reduced Vibration

Vibration can be reduced for the following reasons.
① The vibration characteristic itself is reduced.
② Through speed reduction, the low-speed region at which the motor vibrates can be avoided.
③ Because the motor is smaller, its own vibration is reduced.



RK564AC-T7.2 Vibration data



RK5913AC Vibration data

●Positioning time

Because this comparison uses an inertia structure that can be driven by the motor itself the advantages of geared type motors for acceleration were not manifest, but the larger the inertia body, the more the geared type motor reduces the acceleration time.

●Positioning angle

For *αSTEP* and **RK** series, since the basic step angle is 0.72°, 30° and 60° positioning was not possible, but since 1/7.2, 1/36, and other speed reduction ratios are available for geared type motors, 30° and 60° positioning are possible. This time, to compare a motor alone and a geared type motor under the same conditions, 45° positioning was used because it can be used by both types of motors.

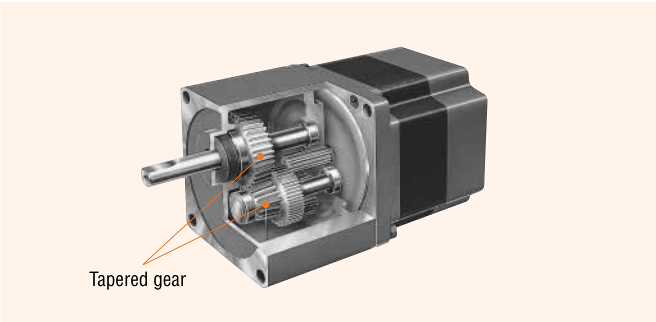
About the Gears

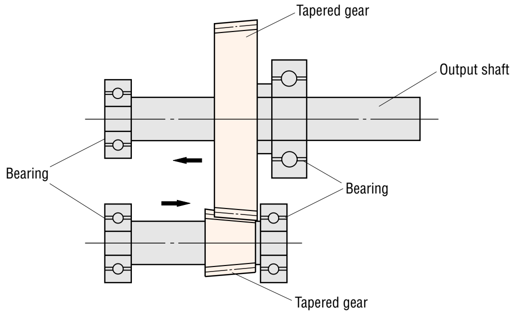
Since the stepping motor and other control motors are designed to allow accurate positioning, the gearheads used for these motors must provide the same level of accuracy. Accordingly, Oriental Motor has developed a mechanism to minimize backlash in gears used with stepping motors in order to ensure low backlash properties.
Generally speaking, a stepping motor features greater output torque than an AC motor of the same frame size. Therefore, the stepping motor is designed to accommodate high torque so as not to diminish the motor's characteristics.
The basic principles and structures of typical control motor gears are explained below.

●TH Gears

◇Principle and Structure

In **TH**-type gears, tapered gears are used for the final stage of the spur gear's speed-reduction mechanism and the meshing gear. The tapered gear is produced through continuous profile shifting toward the shaft. The tapered gears used at the final stage are adjusted in the direction of the arrows, as shown in the figure below, to reduce backlash.



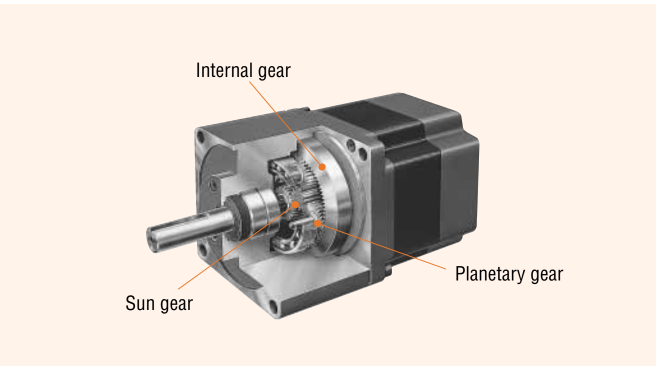


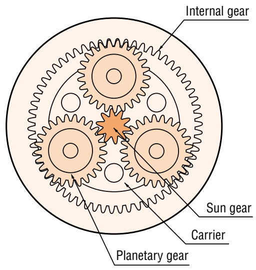
Structure of **TH** gear's final stage

●PL Gears

◇Principle and Structure

The planetary-gear mechanism is comprised mainly of a sun gear, planetary gears and an internal tooth gear. The sun gear is installed on the central axis (in a single-stage type, this is the motor shaft) surrounded by planetary gears enclosed in an internal tooth gear centered on the central axis. The revolution of planetary gears is translated into rotation of the output shaft via carriers.





Cross section of a **PL** gear

Sun gear: A gear located in the center, functioning as an input shaft.
Planetary gears: Several external gears revolving around the sun gear. Each planetary gear is attached to the carrier, onto which the gear's output shaft is securely fixed.
Internal gear: A cylindrical gear affixed to the gearbox, having teeth inside its circular rim.

◇High Permissible Torque

In conventional spur-gear speed-reduction mechanisms gears mesh one to one, so the amount of torque is limited by the strength of each single gear. On the other hand, in the planetary-gear speed-reduction mechanism a greater amount of torque can be transmitted, since torque is distributed through dispersion via several planetary gears.
The torque applied to each gear in the planetary-gear speed-reduction mechanism is obtained through the following formula:

$$T = k\frac{T'}{n}$$

T : Torque applied to each planetary gear (N·m)

T' : Total torque transference (N·m)
n : Number of planetary gears

k : Dispersion coefficient

The dispersion coefficient indicates how evenly the torque is dispersed among the individual planetary gears. The smaller the coefficient, the more evenly the torque is dispersed and the greater the amount of torque that can be transferred. To evenly distribute the transferred torque, each component must be accurately positioned.

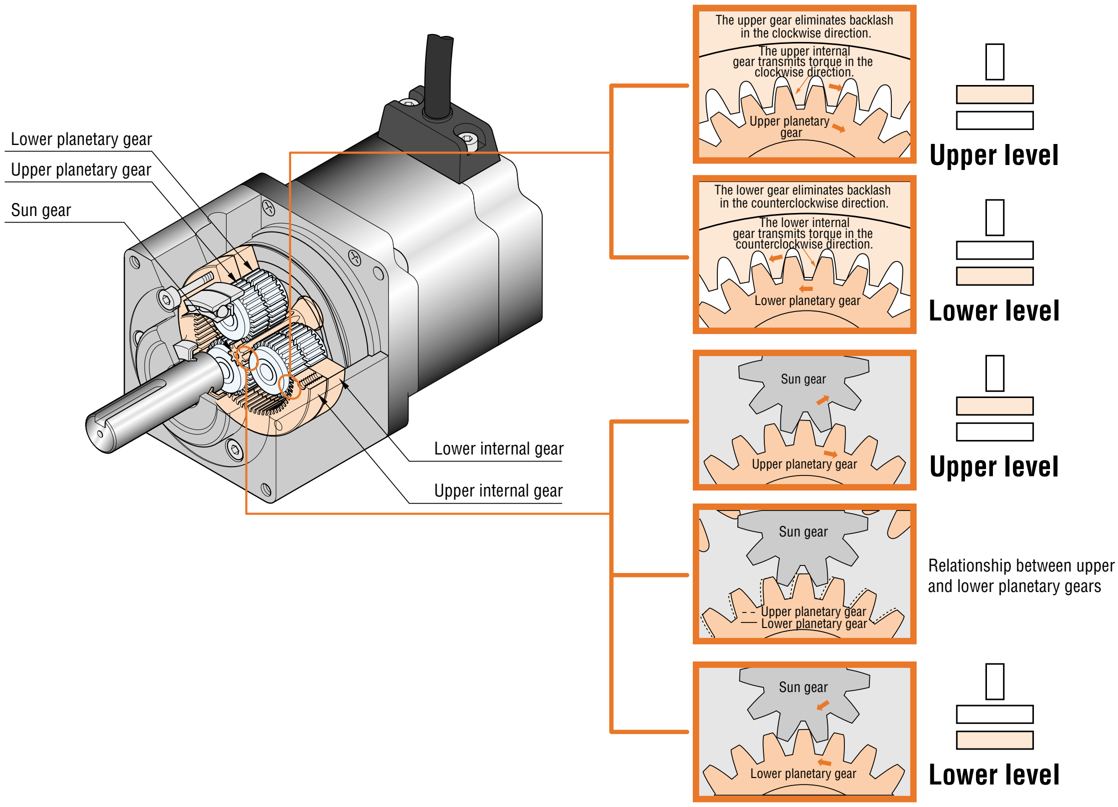
●PN Gears

The **PN** gear was developed for the following purposes:

・Offer the same high level of torque as a **PL** gear.
・Meet the need for highly accurate positioning, which cannot be achieved with a **PL** gear.
・Provide an extensive range of low gear ratios that are difficult to achieve with a harmonic gear.

◇Principle and Structure

The **PN** gear employs the same planetary-gear speed-reduction mechanism as the **PL** gear. The **PN** gear achieves the specified backlash of three arc minutes through the improved accuracy of its components and the backlash-elimination mechanism. That mechanism is comprised of two sets of internal and planetary gears on the upper and lower levels with the internal gear teeth twisted in the circumferential direction. The upper-level internal gears and planetary gears reduce clockwise backlash; the lower-level internal gears and planetary gear reduce counterclockwise backlash.



◇High Permissible Torque

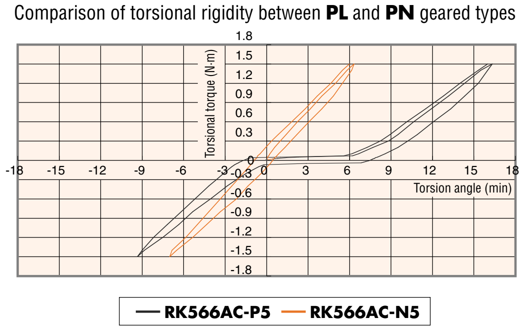
The **PN** gear employs the same planetary-gear speed-reduction mechanism as the **PL** gear. The **PN** gear offers high permissible torque, since it's capable of transmitting torque through dispersion via several planetary gears. For details, read "High Permissible Torque" in the section on the **PL** gear.

◇Gear Characteristics

【Torsional rigidity】

When a load is applied to the **PN** gear's output shaft, displacement (torsion) is proportional to the spring constant. The graph at right shows data for torsion angles measured by gradually increasing and decreasing the load on the output shaft in the forward and backward directions. Since the **PL** gear's specified backlash is 20 arc minutes, even with minimal torsional torque the torsion angle will abruptly increase in accordance with the amount of backlash. On the other hand, since the **PN** gear's backlash is maintained at or below three arc minutes, the torsional torque will not result in an abrupt increase in torsion angle.

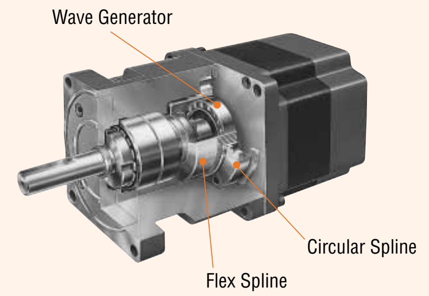
Comparison of torsional rigidity between **PL** and **PN** geared types



●Harmonic Gears

◇Principle and Structure

The harmonic gear offers unparalleled precision in positioning and features a simple construction utilizing the metal's elastomechanical property, comprising just three basic components: a wave generator, flex spline and circular spline.



Wave Generator

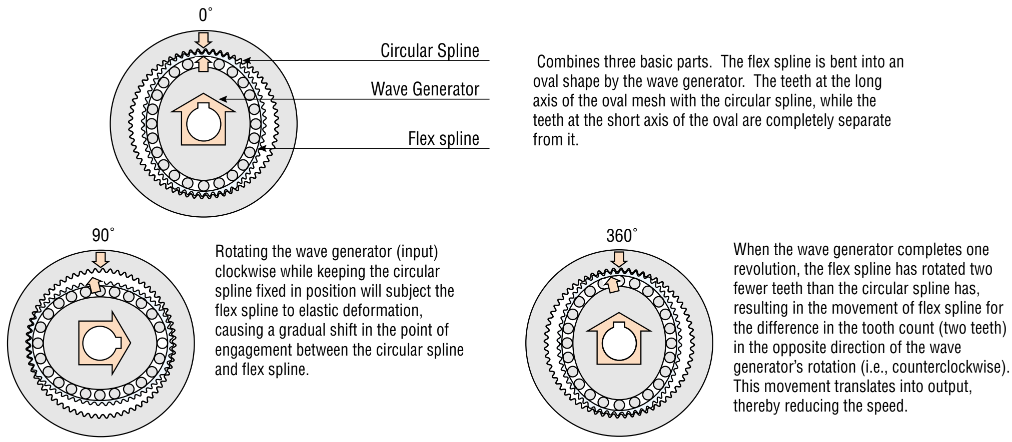
The wave generator is an oval-shaped component with a thin ball bearing placed around the outer circumference of the oval cam. The bearing's inner ring is attached to the oval cam, while the outer ring is subjected to elastic deformation via the balls. The wave generator is mounted onto the motor shaft.

Flex Spline

The flex spline is a thin, cup-shaped component made of elastic metal, with teeth formed along the outer circumference of the cup's opening. The gear's output shaft is attached to the bottom of the flex spline.

Circular Spline

The circular spline is a rigid internal gear with teeth formed along its inner circumference. These teeth are the same size as those of the flex spline, but the circular spline has two more teeth than the flex spline. The circular spline is attached to the gearbox along its outer circumference.

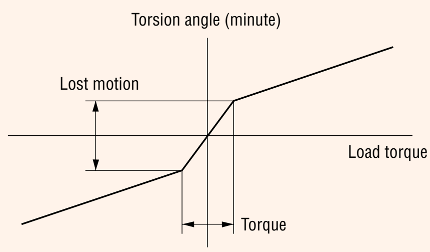


◇Precision

Unlike conventional spur gears, the harmonic gear is capable of averaging the effects of tooth-pitch errors and accumulated pitch errors to the rotational speed, thus achieving highly precise, zero-backlash performance. However, the gear's own torsion may become the cause of a problem when performing ultra-high-precision positioning at an accuracy of two arc minutes or less. When using a harmonic gear for ultra-high-precision positioning, remember the following three points:

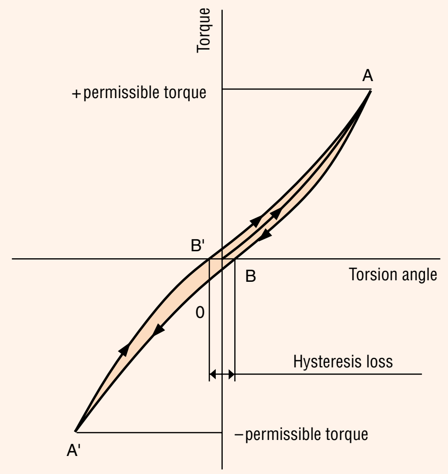
Lost Motion

Lost motion is the total value of the displacement produced when about five percent of permissible torque is applied to the gear's output shaft. Since harmonic gears have no backlash, the measure indicating the gear's precision is represented as lost motion.



Hysteresis Loss

When torsion torque is gradually applied to the gear output shaft until it reaches the permissible torque in the clockwise or counterclockwise direction, the angle of torsion will become smaller as the torque is reduced. However, the angle of torsion never reaches zero, even when fully returned to its initial level. This is referred to as "hysteresis loss," as shown by B-B' in the figure.
Harmonic gears are designed to have a hysteresis loss of less than two minutes. When positioning from the clockwise or counterclockwise direction, this hysteresis loss occurs even with a frictional coefficient of 0. When positioning to two minutes or less, positioning must be done from a single direction.



Torsion angle and torque characteristics

Torque and Torsion Characteristics

Displacement (torsion) is produced by the gear's spring constant when a load is applied to the output shaft of the harmonic gear. The amount of this displacement, which is caused when the gear is driven under a frictional load, is the same as the value when the motor shaft is held fixed and torsion (torque) is applied to the gear's output shaft. The amount of displacement (torsion angle) can be estimated through use of an equation, as shown below.

Calculation method
The harmonic gear's torsion-angle/torque-characteristic curve is not linear, and the characteristics can be expressed in one of the following three equations depending on the load torque:

1. Load torque T_L is T_1 or less.

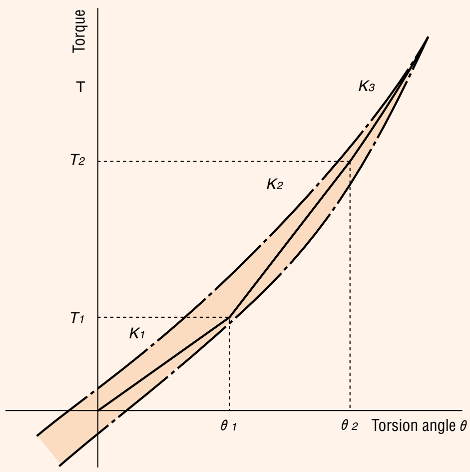
$$\theta = \frac{T_L}{K_1} \text{〔min.〕}$$

2. Load torque T_L is greater than T_1 but not larger than T_2.

$$\theta = \theta_1 + \frac{T_L - T_1}{K_2} \text{〔min.〕}$$

3. Load torque T_L is greater than T_2.

$$\theta = \theta_1 + \theta_2 + \frac{T_L - T_1 - T_2}{K_2} \text{〔min.〕}$$



Torsion angle and torque characteristics

Torsion angles obtained by these equations are for individual harmonic gears.

Values for Determining Torsion Angle

Item / Model	Gear ratio	T_1 N·m	K_1 N·m/min.	θ_1 min	T_2 N·m	K_2 N·m/min.	θ_2 min.	K_3 N·m/min.
AS66□□-H50	1 : 50	2.0	1.0	2.0	7.0	1.4	5.6	1.7
AS66□□-H100	1 : 100	2.0	1.4	1.4	7.0	1.8	4.2	2.1
AS98□□-H50	1 : 50	7.0	3.8	1.8	25	5.2	5.3	6.7
AS98□□-H100	1 : 100	7.0	4.7	1.5	25	7.5	3.9	8.5

Useful Life of a Gearhead

The useful life of a gearhead is reached when power can no longer be transmitted because the bearing's mechanical life has ended. Therefore, the actual life of a gearhead varies depending on the load size, how the load is applied, and the allowable speed of rotation. Oriental Motor defines service life under certain conditions as "rated lifetime," based on which the useful life under actual operation is calculated according to load conditions and other factors.

●Rated Lifetime

Oriental Motor defines the rated lifetime as the useful life of a gearhead under the following operating conditions:

[Operating conditions]
Torque: Permissible torque
Load: Uniform continuous load
Input rotational speed: Reference-input rotational speed
Rotational speed at the rated lifetime of each gear type
Overhung load: Permissible overhung load
Thrust load: Permissible thrust load

[Table 1: Rated Lifetime per Gear Type]

Series/Motor type	Gear type	Reference-input rotational speed	Rated lifetime (L1)
αSTEP	**TH** geared type	1500r/min	5000 hrs.
	PL geared type		
	Harmonic geared type		
RK series	**TH** geared type		
	PN geared type		
	Harmonic geared type		
5-phase **CSK** Series	**TH** geared type		
2-phase **CSK** Series	**SH** geared type		
2-phase **PK** Series	**SH** geared type		
PMC series	**MG** geared type	3000r/min	5000 hrs.
	Harmonic geared type		2500 hrs.

●Estimating Lifetime

Lifetime under actual conditions of use is calculated based on the permissible rotational speed, load size and load type, using the following formula:

$$L(\text{lifetime}) = L_1 \times \frac{K_1}{(K_2)^3 \times f} \ [\text{h}]$$

L_1: Rated lifetime [hrs.]
See Table 1 to find the applicable rated lifetime from the type of gear.

K_1: Rotational speed coefficient
The rotational speed coefficient (K_1) is calculated based on the reference-input rotational speed listed in Table 1 and the actual-input rotational speed.

$$K_1 = \frac{\text{Reference-input rotational speed}}{\text{Actual-input rotation speed}}$$

K_2: Load factor
The load factor (K_2) is calculated based on actual operating torque and the allowable torque for each gear.
The average torque may be considered operating torque if the gear is subjected to load while starting and stopping only, as when driving an inertial body. The calculation of average torque is explained later in this section.

$$K_2 = \frac{\text{Operating torque}}{\text{Permissible torque}}$$

Permissible torque is per the specified values listed in the product catalogue and operating manual.

f: Load-type factor
The factor (f) may be determined based on load type, using the following examples as a reference:

Load type	Example	Factor (f)
Uniform load	・One-way continuous operation ・For driving belt conveyors and film rollers that are subject to minimal load fluctuation.	1.0
Light impact	・Frequent starting and stopping ・Cam drive and inertial body positioning via stepping motor	1.5
Medium impact	・Frequent instantaneous bidirectional operation, starting and stopping of reversible motors ・Frequent instantaneous starting and stopping of brushless motors	2.0

《Notes regarding the effects of overhung load and thrust load》

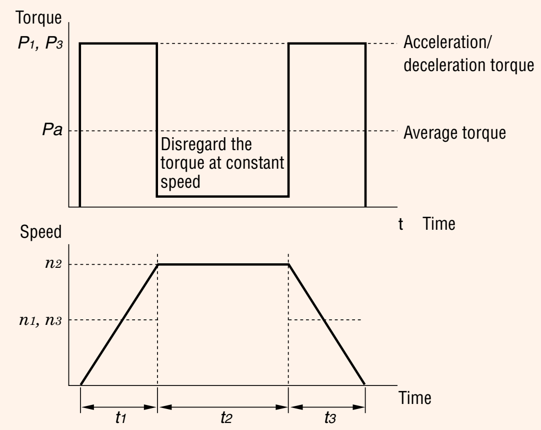
- The above estimated lifetime is calculated according to the overhung and thrust loads, which are in proportion to a given load factor. For example, if the load factor is 50 percent, the lifetime is calculated using 50-percent overhung and thrust loads.
- The actual life of a gearhead having a low load factor and a large overhung or thrust load will be shorter than the value determined through the above equation.

●How to Obtain the Average Torque

The stepping motor is used for intermittent operation of an inertial body, such as driving an index table and arm. If the stepping motor is used in such an application, the average torque shall be considered the operating torque, as described below.
The load factor for driving an inertial body using an AC motor or BL motor shall be 1.0.

◇Driving an Inertial Body Only ①

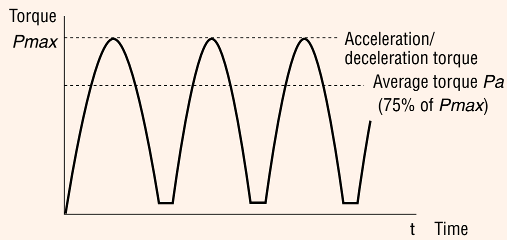
The graph at right shows torque generated in order to drive an inertial body over a long operating cycle. Friction load caused by bearings and other parts during constant-speed operation are negligible.



$$Pa=\sqrt[3]{\frac{(P_1{}^3\times n_1\times t_1)+(P_3{}^3\times n_3\times t_3)}{(n_1\times t_1)+(n_2\times t_2)+(n_3\times t_3)}}$$

◇Driving an Inertial Body Only ② : Driving an Arm or Similar Object

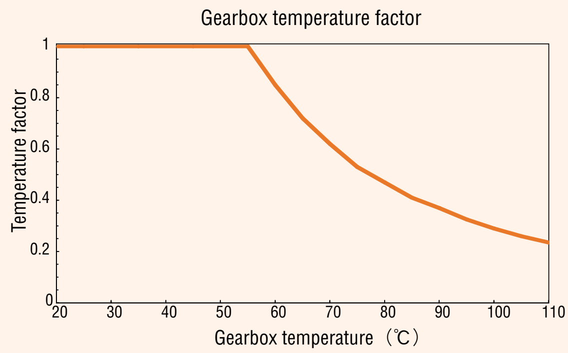
When driving an arm or similar object, the gearhead may be subjected to load fluctuation as shown in the graph.
For example, such load fluctuation will occur when driving a double-joint arm or moving an arm in the vertical direction.
In such an application the average torque shall be 75 percent of the maximum acceleration/deceleration torque, as shown in the equation below.



$$Pa=Pmax\times 0.75$$

●Operating Temperature

An increase in gearhead temperature affects the lubrication of the bearing. However, since the effect of temperature on gearhead life varies according to the condition of the load applied to the gearhead bearings, model number and many other factors, it is difficult to include the temperature effect in the equation to estimate the lifetime, which was described earlier.
The graph shows the temperature effect on the gearhead bearings. The gearhead life is affected when the gearbox's surface temperature is 55˚C or above.



●Notes

In some cases a lifetime of several ten thousand hours may be obtained from the calculation. Use the estimated life as a reference only.
The above life estimation is based on the reasoning of bearing life.
An application in excess of the specified value may adversely affect parts other than the bearings. Use the product within the range of specified values listed in the product catalogue or operating manual.