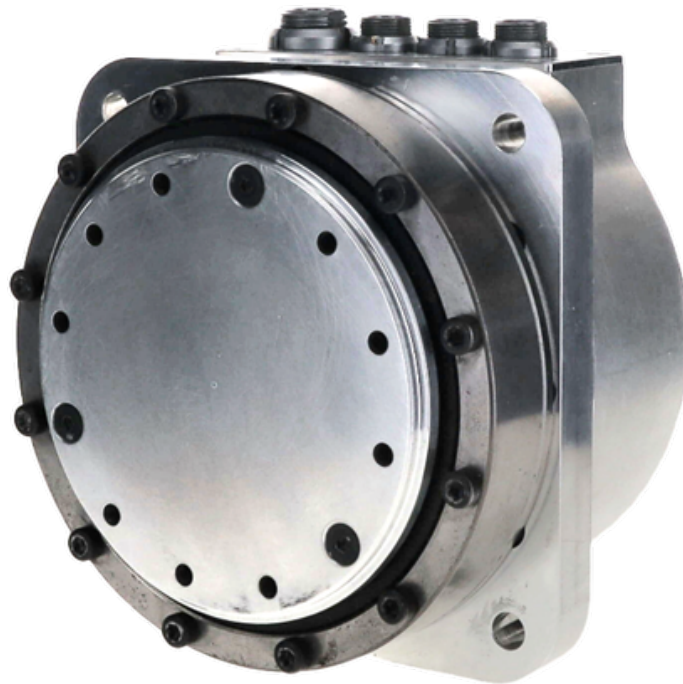


Harmonic Drive[®]

MECHATRONICS

Low Profile Rotary Actuator with Integrated Servo Drive

L P A s e r i e s m a n u a l



CE



Introduction

Thank you for purchasing our LPA series AC Servo Actuator.

Wrong handling or use of this product may result in unexpected accidents or shorter life of the product. Read this document carefully and use the product correctly so that the product can be used safely for many years.

Product specifications are subject to change without notice for improvement purposes.

Company names and product names in this document are generally registered trademarks or trademarks of their respective companies.

Keep this manual in a convenient location and refer to it whenever necessary in operating or maintaining the units.



The end user of the actuator should have a copy of this manual.

SAFETY GUIDE

To use this actuator safely and correctly, be sure to read SAFETY GUIDE and other parts of this document carefully and fully understand the information provided herein before using the actuator.

NOTATION

Important safety information you must note is provided herein. Be sure to observe these instructions.

 WARNING	Indicates a potentially hazardous situation, which, if not avoided, could result in death or serious personal injury.
 CAUTION	Indicates a potentially hazardous situation, which, if not avoided, may result in minor or moderate personal injury and/or damage to the equipment.
Caution	Indicates what should be performed or avoided to prevent non-operation or malfunction of the product or negative effects on its performance or function.

LIMITATION OF APPLICATIONS

The equipment listed in this document may not be used for the applications listed below:

- Space equipment
- Automobile, automotive parts
- Aircraft, aeronautic equipment
- Amusement equipment, sport equipment, game machines
- Nuclear equipment
- Machine or devices acting directly on the human body
- Household apparatus
- Instruments or devices to transport or carry people
- Vacuum equipment
- Apparatus or devices used in special environments

If the above list includes your intending application for our products, please consult us.



Safety measures are essential to prevent accidents resulting in death, injury or damage of the equipment due to malfunction or faulty operation.

SAFETY NOTE

ITEMS YOU SHOULD NOTE WHEN USING THE ACTUATOR

● CAUTIONS RELATED TO THE DESIGN



Always use under followings conditions.

The actuator is designed to be used indoors. Observe the following conditions:

- Ambient temperature: 0 to 40 °C
- Ambient humidity: 20 to 80 %RH (Non-condensation)
- Vibration: Max 25 m/s²
- No contamination by water, oil
- No corrosive or explosive gas

Follow exactly the instructions in the relating manuals to install the actuator in the equipment.

- Ensure exact alignment of the actuator center and the center of the corresponding machine by following the manual.
- Failure to observe this caution may lead to vibration, resulting in damage of output elements.

● CAUTIONS FOR USAGE



Keep limited torques of the actuator.

- Keep limited torques of the actuator.
- Be aware, that if arms attached to output element hits by accident an solid, the output element may be uncontrollable.

Never connect cables directly to a power supply socket.

- Each actuator must be operated with a proper servo amplifier.
- Failure to observe this caution may lead to injury, fire or damage of the actuator.

Do not apply impacts and shocks

- The actuator directly connects with the encoder so do not use a hammer during installation.
- Failure to observe this caution could damage the encoder and may cause uncontrollable operation.

Avoid handling of actuators by cables.

- Failure to observe this caution may damage the wiring, causing uncontrollable or faulty operation.

ITEMS YOU SHOULD NOTE WHEN USING THE INTEGRATED DRIVER

● OPERATIONAL PRECAUTIONS



Never change any wiring while the power is active.

Make sure that the power is not active before servicing the products. Failure to observe this caution may result in an electric shock or uncontrollable operation.

Do not touch the terminals for at least 15 minutes after turning OFF the power supply.

- Even after the power supply is turned OFF, electric charge remains in the servo amplifier. In order to prevent electric shock, perform inspections 15 minutes or more after the power supply is turned OFF.
- When installing, make sure that the inner electronic components are hard to reach.

DISPOSAL



All products or parts have to be disposed of as industrial waste.

Since the case or the box of drivers have a material indication, classify parts and dispose them separately.

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Related manuals

The table below lists related manuals. Check each item as necessary.

Title	Document No.	Description
Harmonic Drive LLC Integrated Drive Technology EtherCAT® Firmware Manual	TI-25001	EtherCAT® communication and firmware object specifications explained.
Harmonic Drive LLC Integrated Drive Technology CANopen® Firmware Manual	TI-18002	CANopen® communication and firmware object specifications explained.
SHA SG/CG series manual	-	The specifications and characteristics of SHA SG/CG series are explained.



Conformance to overseas standards

The LPA series actuator conforms to following overseas standards.

Safety of Machinery	EN ISO 12100
Rotating Electrical Machines - Part 1	EN 60034-1
Adjustable speed electrical power drive systems – Part 3	EN 61800-3

Chapter 1

Outlines

This chapter explains the features, functions and specifications of the actuator.

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1-1 Overview

The series of Integrated Servo Actuators provide high torque and high accuracy rotary motion. These Servo Actuators are each composed of a Harmonic Drive® speed reducer for precise control and a flat, high performance servo motor with dual absolute multi-turn encoders, and an integrated servo drive. The LPA series Integrated Actuators feature a slim, compact design.

LPA Series Integrated Servo Actuators incorporate SHD series speed reducers. They are axially compact and feature a robust cross roller bearing so loads can be mounted directly to the unit without the need for additional support bearings.

One key feature of the LPA actuators is their compact size. The thickness has been minimized, providing a maximum torque/volume ratio which is approximately double that of conventional FHA actuators.

LPA series actuators include a dedicated servo drive for position/speed/torque control incorporated into the housing and developed exclusively for driving LPA series actuators. These integrated drivers control the LPA series actuators' operations with great accuracy and precision.

◆ Improved Torque Density

High-torque SHD series Harmonic Drive® speed reducers are incorporated into the actuator for precise control and the thickness of the actuator has been reduced by approximately 50% compared to our conventional products. As a result, the maximum torque/volume ratio has approximately doubled compared to our previous actuator designs. Also, the output torque is much higher when compared with direct drive motors of similar volume/weight.

◆ Modular Design

The components of the LPA series, such as speed reducers, output shaft bearing, motor, encoders, and integrated servo drive, are arranged based on a modular design. We can custom-design a model to meet your specific requirements, so please contact your HDLLC sales representative.

◆ Standard 15-bit input, 14 bit output, dual absolute encoders

LPA series actuators are equipped with Harmonic Drive's patented dual absolute encoder technology, with highly reliable 15 bit input and 14 bit output magnetic absolute encoders.

◆ Supporting open network control

The integrated servo drive supports EtherCAT® and CANopen® fieldbus options.

◆ Simplified Cabling

For CANopen® option, only a single cable with four conductors is needed for power and communication.

◆ Dedicated Harmonic Drive HDL Commissioning Software

HDL-IDE software provides the ability to setup or commission the LPA Integrated actuators without connecting to a CANopen® or EtherCAT® master controller. A single actuator can connect to a personal computer or laptop with a CAN communication converter and a power supply. All 256 parameters, including the tuning parameters and 256 general user variables can be set and stored to be recognized by the master controller operating the specific application.

1-2 Model

Model names for LPA series actuators are explained below.



1.	Model	LPA Integrated Series
2.	Size	20
3.	Design Version	A
4.	Gear Ratio	51, 81, 101
5.	Encoder and Resolution	15b14b - Integrated Drive Motor Input Encoder (15bit), Gear Output Encoder (14bit)

6.	Options	PM1 – Axial Exit PM4 – Radial Exit
7.	Communication and I/O Connection Signal	Blank: CANopen® Option S: CANopen® with IO & MTO Option E: EtherCAT® Option ES: EtherCAT® with IO & MTO Option
8.	Special Specifications	Blank: Standard Product SP: Special Specification Code

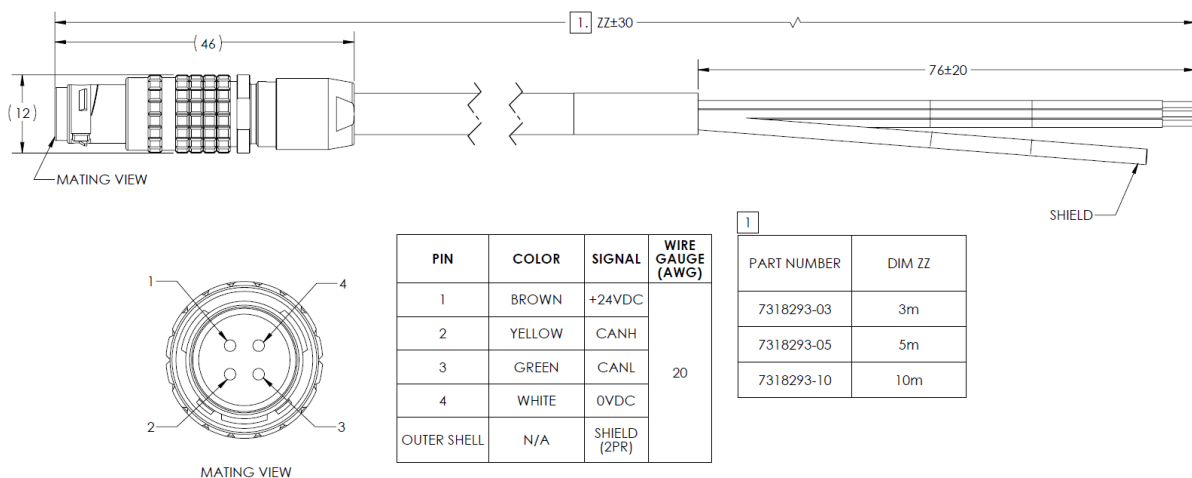
1-3 Cables

The following outlines standard cabling options for LPA series actuators. Contact us for additional information.

CANopen® Cables

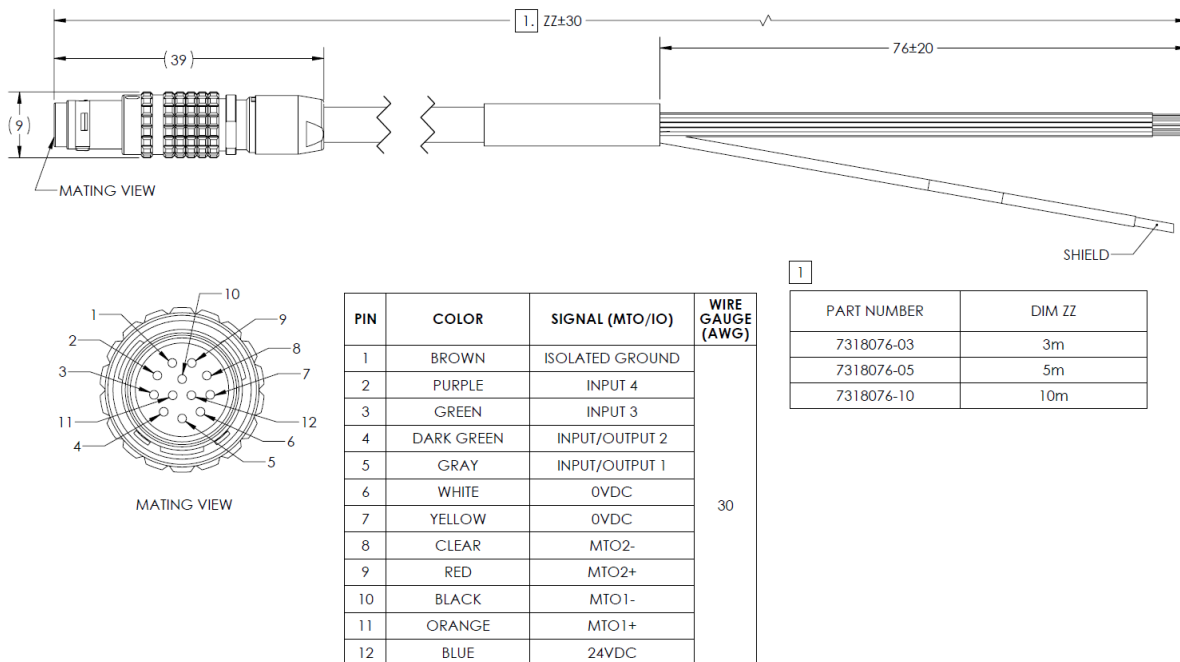
Power and Communication

CBL-DZZ-L104-N



IO/MTO Cable (Optional)

CBL-EZZ-L012-N

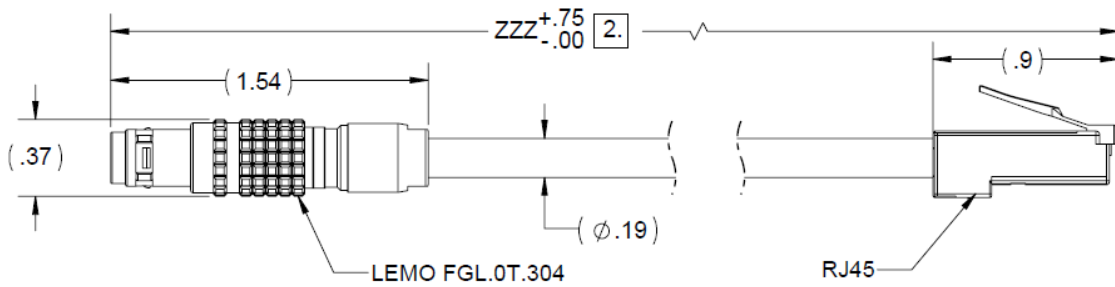


EtherCAT® Cables

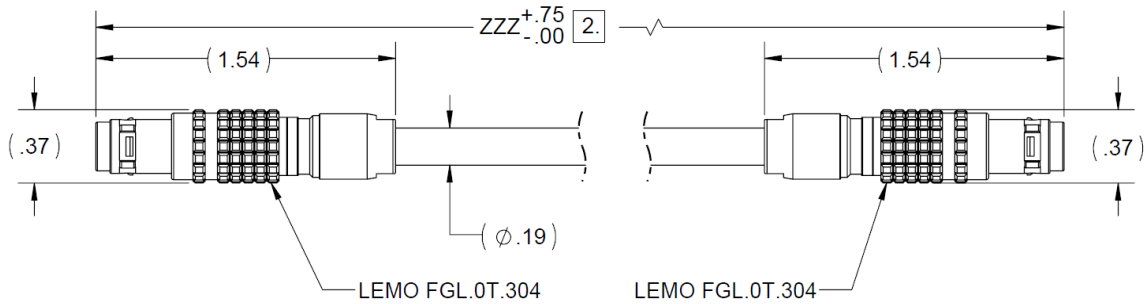
Communication

Suitable for Burst Noise Levels 1-2*

7318549-ZZZ

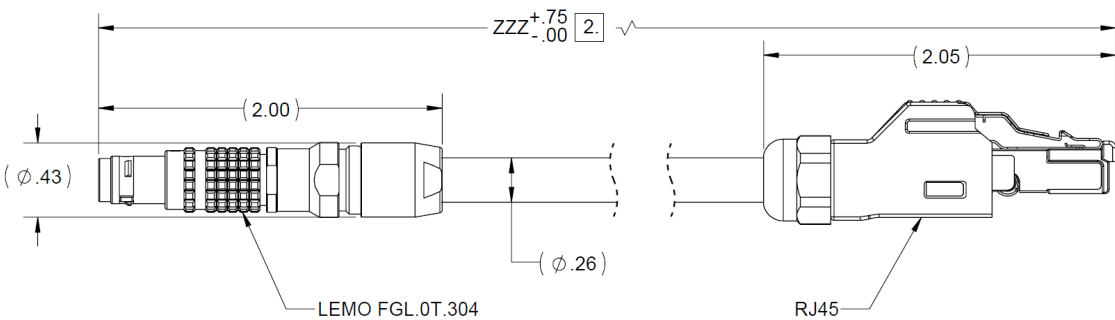


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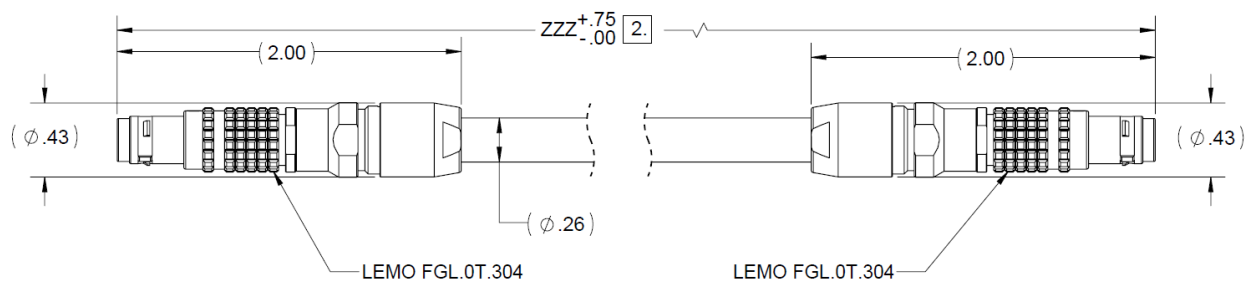


Suitable for Burst Noise Levels 1-3*

7318571-ZZZ



7318572-ZZZ



* As defined by IEC 61000-4-4. See burst noise test levels table for more information.

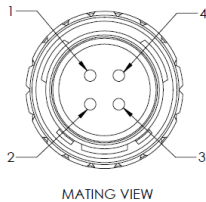
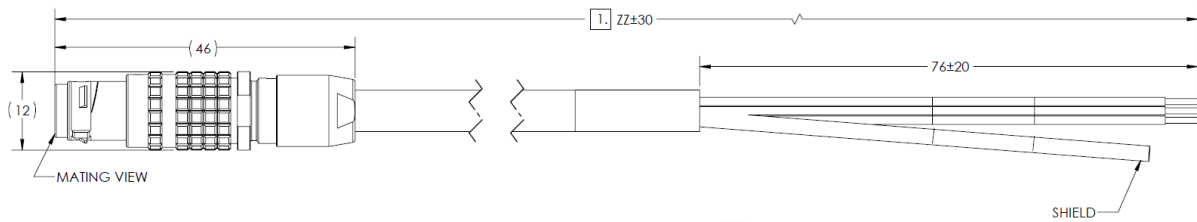
Burst Noise Levels

BURST NOISE TEST LEVELS AS DEFINED BY IEC 61004-4		
LEVEL	VOLTAGE PEAK (KV)	REPETITION RATE (KHZ)
1	0.25	5
2	0.5	5
3	1	5

Part Number Table

PART NUMBER TABLE 2.		
P/N	DESCRIPTION	LENGTH ZZZ
7318549-120	CABLE 4 PIN LEMO FEMALE FGL.0T.304.CYMC50 ETHERCAT 4C	120 in / 10 ft
7318549-225		225 in / 15 ft
7318549-360		360 in / 30 ft
7318571-120	CABLE 4 PIN LEMO FEMALE FGL.0T.304.CYMK65 ETHERCAT 2P	120 in / 10 ft
7318571-225		225 in / 15 ft
7318571-360		360 in / 30 ft
7318565-120	CABLE 4 PIN LEMO TO LEMO FGL.0T.304.CYMC50 ETHERCAT 4C	120 in / 10 ft
7318565-225		225 in / 15 ft
7318565-360		360 in / 30 ft
7318572-120	CABLE 4 PIN LEMO TO LEMO FGL.0T.304.CYMK65 ETHERCAT 2P	120 in / 10 ft
7318572-225		225 in / 15 ft
7318572-360		360 in / 30 ft

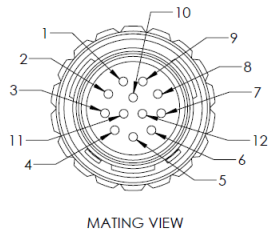
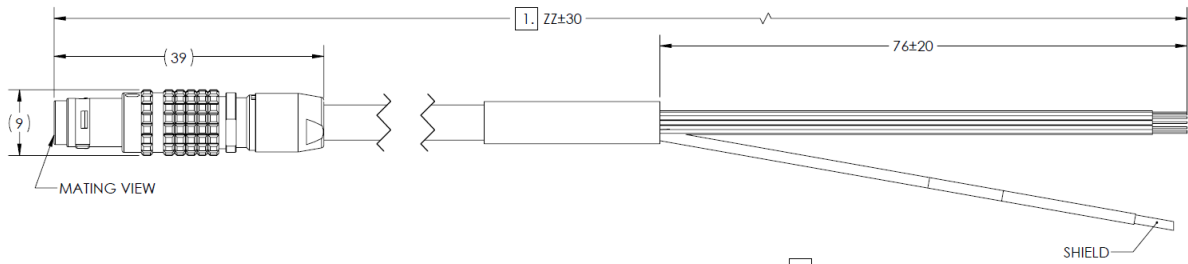
Power



PIN	COLOR	SIGNAL	WIRE GAUGE (AWG)
1	BROWN	+24VDC	20
2	YELLOW	-	
3	GREEN	-	
4	WHITE	0VDC	
OUTER SHELL	N/A	SHIELD (2PR)	

PART NUMBER	DIM ZZ
7318293-03	3m
7318293-05	5m
7318293-10	10m

IO/MTO Cable (Optional)



PIN	COLOR	SIGNAL (MTO/IO)	WIRE GAUGE (AWG)
1	BROWN	ISOLATED GROUND	30
2	PURPLE	INPUT 4	
3	GREEN	INPUT 3	
4	DARK GREEN	INPUT/OUTPUT 2	
5	GRAY	INPUT/OUTPUT 1	
6	WHITE	0VDC	
7	YELLOW	0VDC	
8	CLEAR	MTO2-	
9	RED	MTO2+	
10	BLACK	MTO1-	
11	ORANGE	MTO1+	
12	BLUE	24VDC	

1	
PART NUMBER	DIM ZZ
7318076-03	3m
7318076-05	5m
7318076-10	10m

1-4 Specifications

The specifications of LPA series actuators are explained.

Gear Ratio		Item	LPA 20 IDT Actuator		
			51	81	101
Maximum torque	Nm	34	49	57	
Maximum speed	rpm	88.2	55.6	44.6	
Maximum current	A_{rms}	13.4	13.4	11.5	
Continuous torque ¹	Nm	6.5	16	16.9	
Continuous speed ¹	rpm	58.8	37.0	29.7	
Continuous current ¹	A_{rms}	4.5	4.5	4	
Torque constant	Nm/A_{rms}	3.0	4.8	6.0	
Input power supply current	A _{dc}	2.7	3.0	2.4	
Moment of inertia	kgm ²	0.02	0.06	0.09	
Allowable moment load	Nm	93			
Moment stiffness	Nm/rad	21 x 10 ⁴			
Output bearing basic dynamic rated load	kN	7.3			
Encoder type	–	Dual Absolute			
Motor encoder resolution	–	2 ¹⁵ (32768)			
Gear encoder resolution	–	2 ¹⁴ (16384)			
Mass	kg	1.4			
Operating voltage	V	48 (24-60)			
Communication protocol	–	CANopen® (DS301/DS402), EtherCAT®			
Environmental	Ambient operating temp	°C	0-40 (-20 - 60 storage)		
	Ingress protection rating	–	IP54		
	Operating humidity	%RH	20-80 (no condensation)		
	Vibration resistance ²	m/s ²	25		
	Shock resistance ²	m/s ²	300		
	Max operating altitude	m	1000		
No dust, no metal powder, no corrosive gas, no flammable gas, no oil mist, Indoor use only, no direct sunlight					
Motor insulation	Insulation resistance: 100MΩ (by DC500V insulation tester), Dielectric strength: AC1500v/1 min Insulation class: F				
Mounting direction	Can be installed in any direction				
Recommended heatsink size [mm] ¹	300 X 300 X 15 mm				

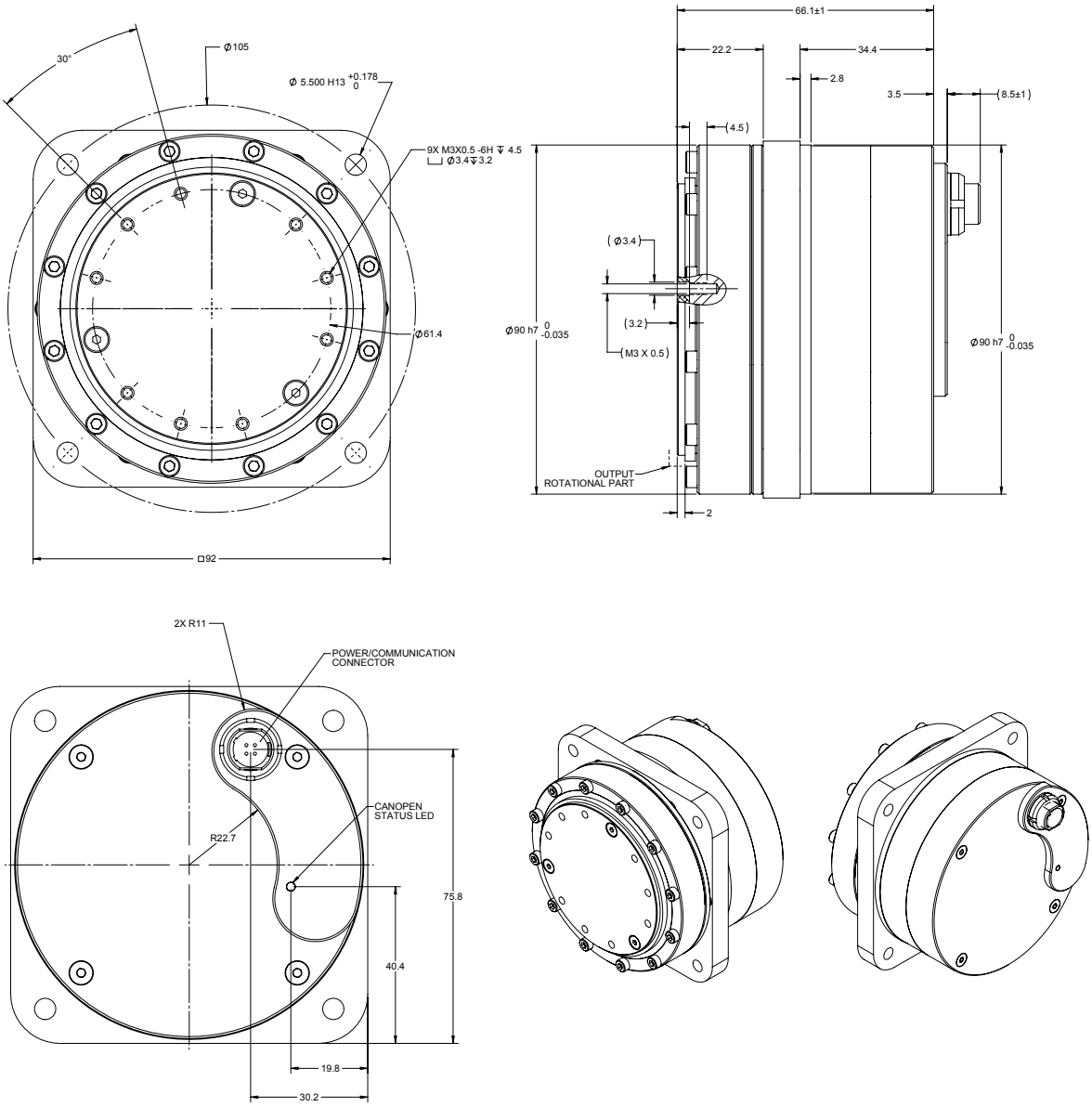
1. Value after temperature rise and saturation when the recommended aluminum heatsink is installed.

2. All parts, except the rotary sliding parts (oil seal), are protected against solid bodies of dimensions to 1mm, and against water sprays. Panel mount connectors are IP68.

1-5 External dimensions

The external dimensions of LPA series actuators are shown below.

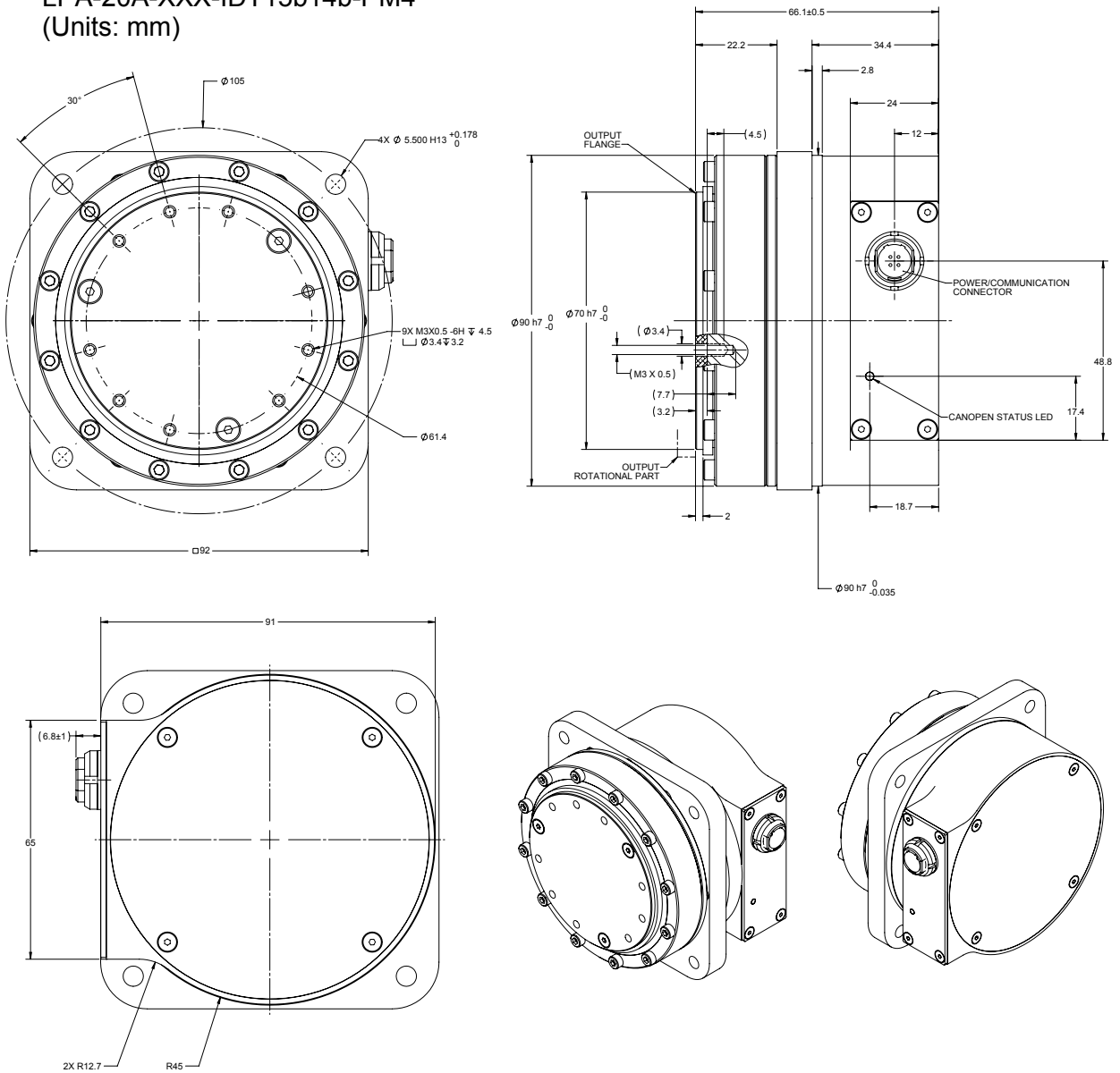
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(Units: mm)



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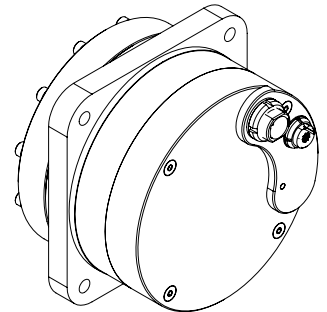
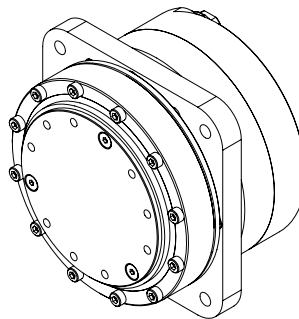
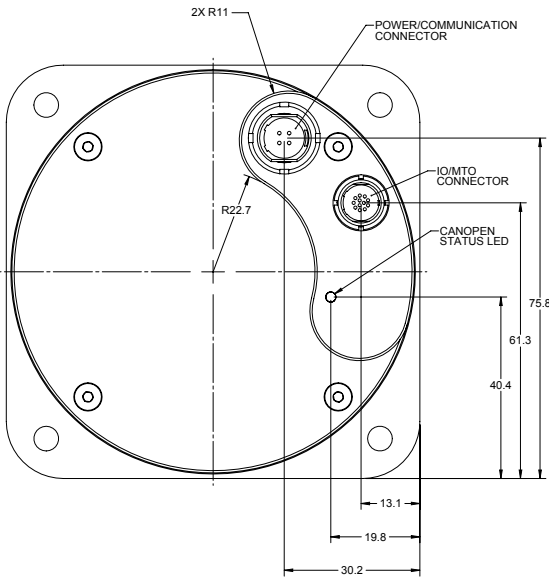
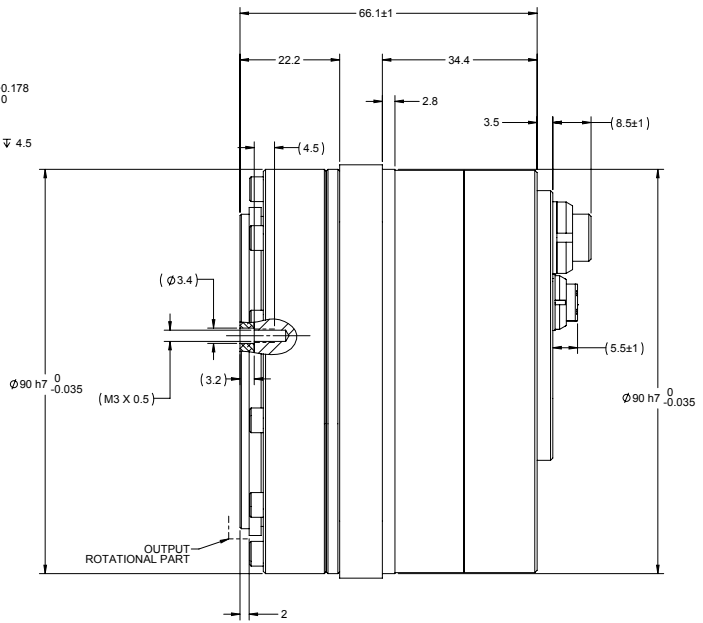
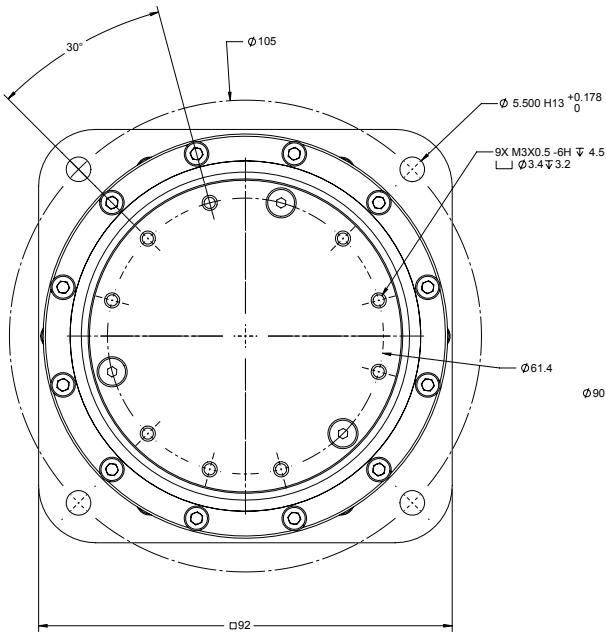
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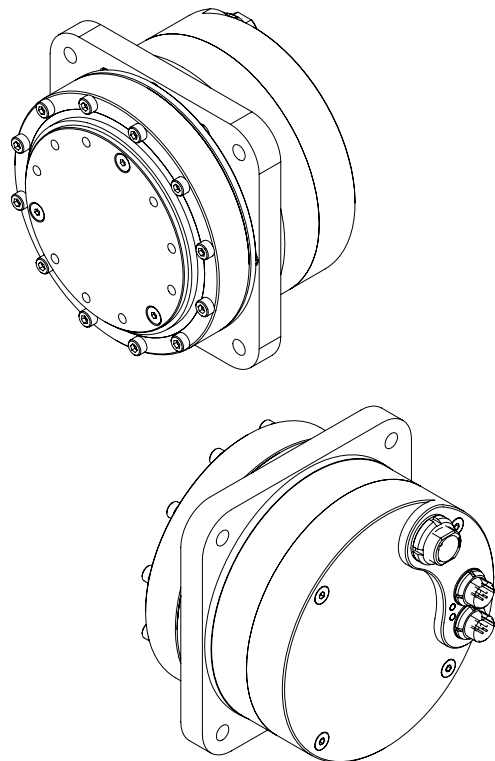
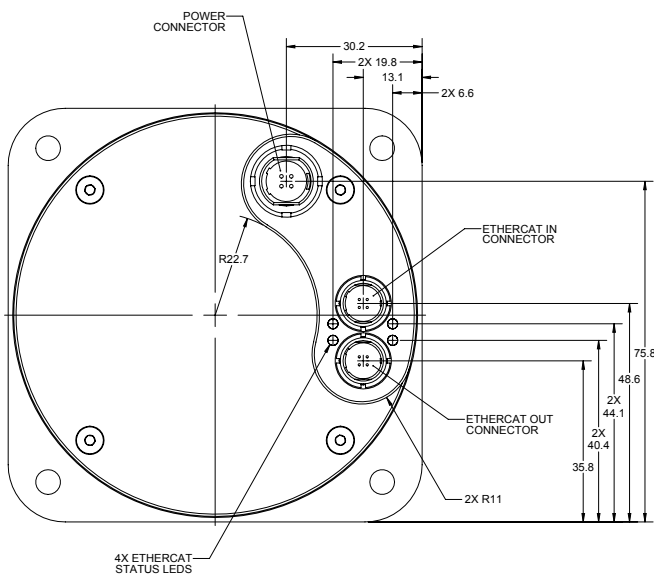
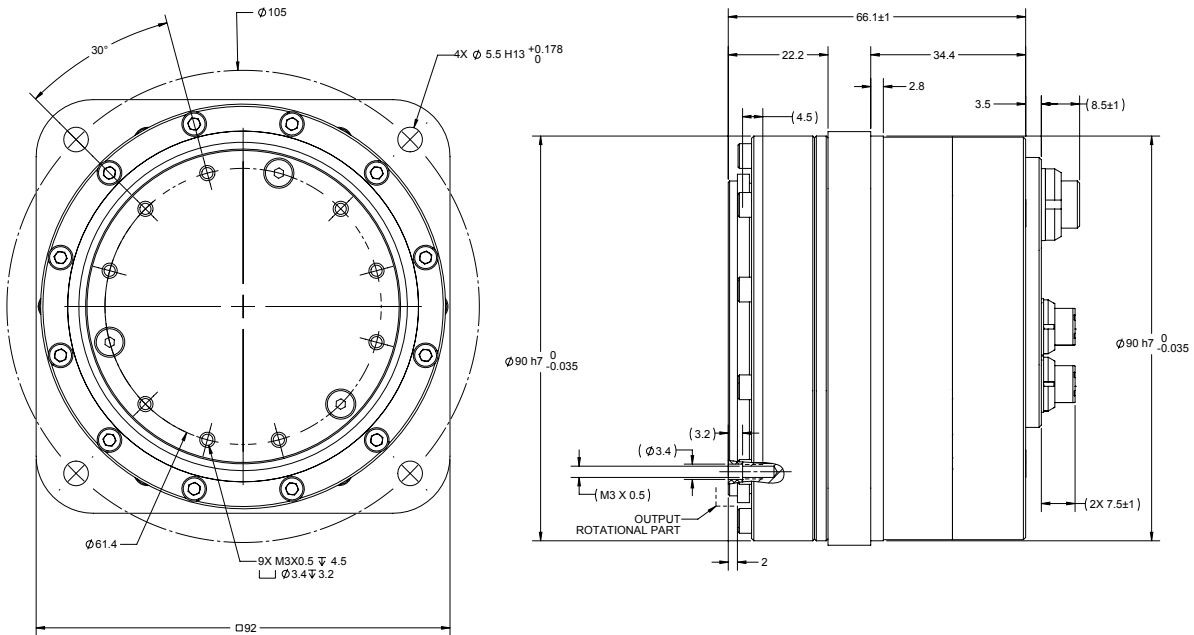
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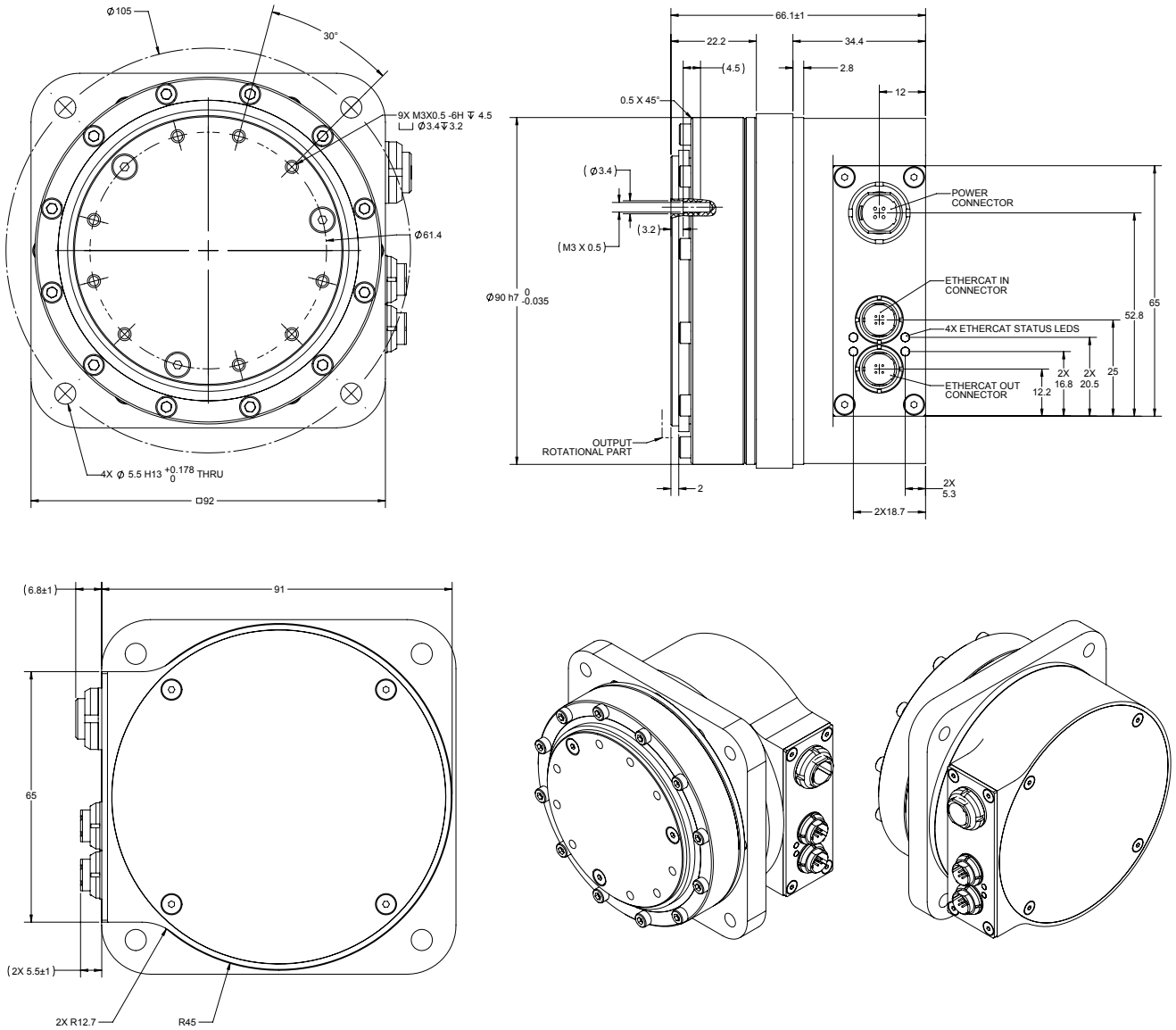
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1

Outlines

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(Units: mm)



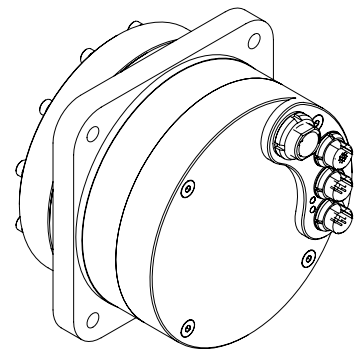
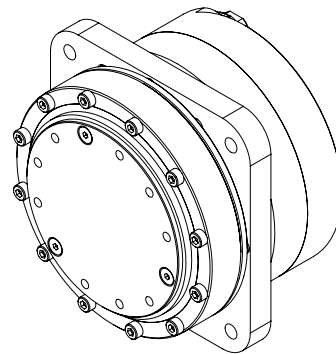
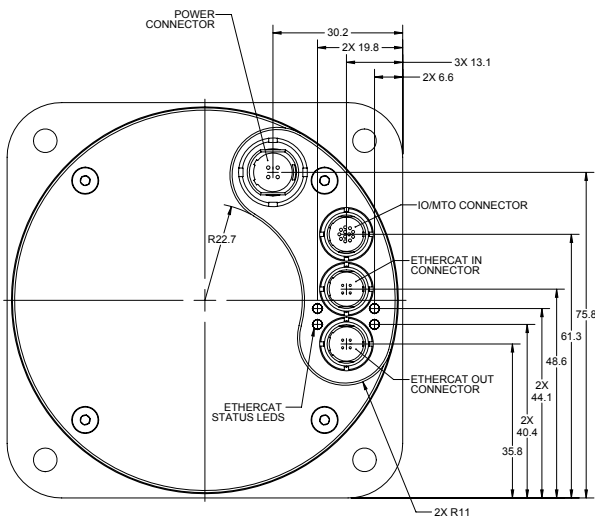
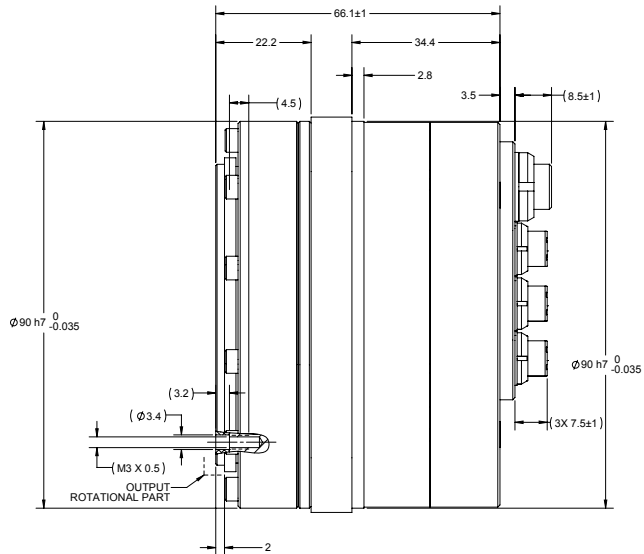
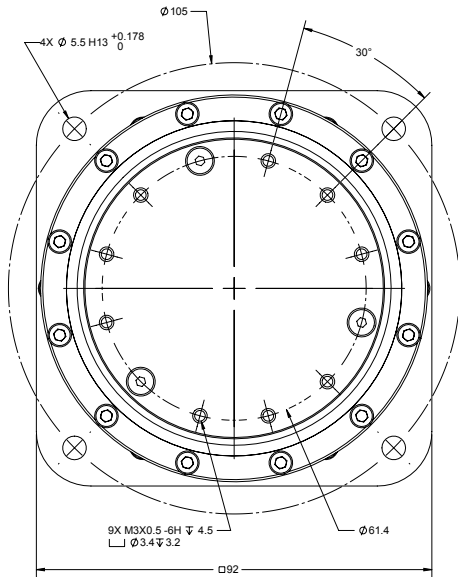
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(Units: mm)



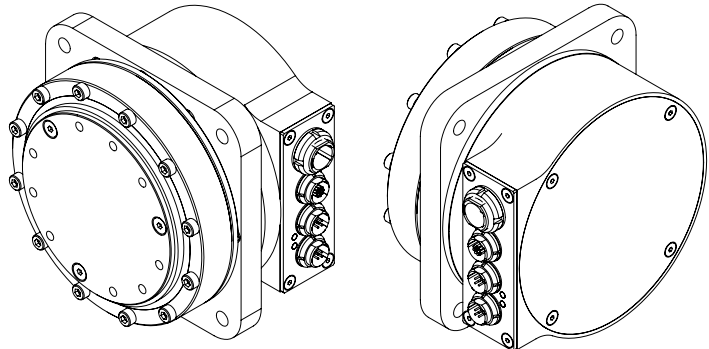
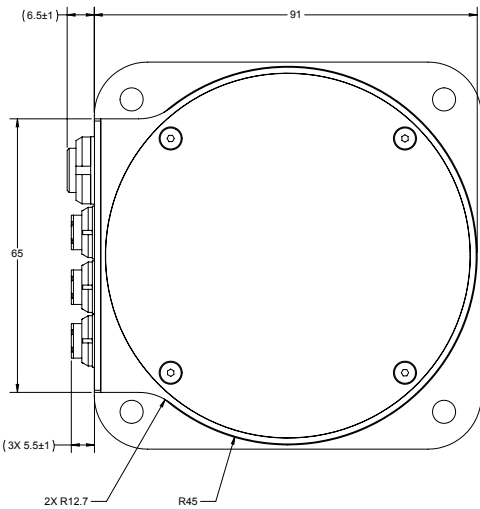
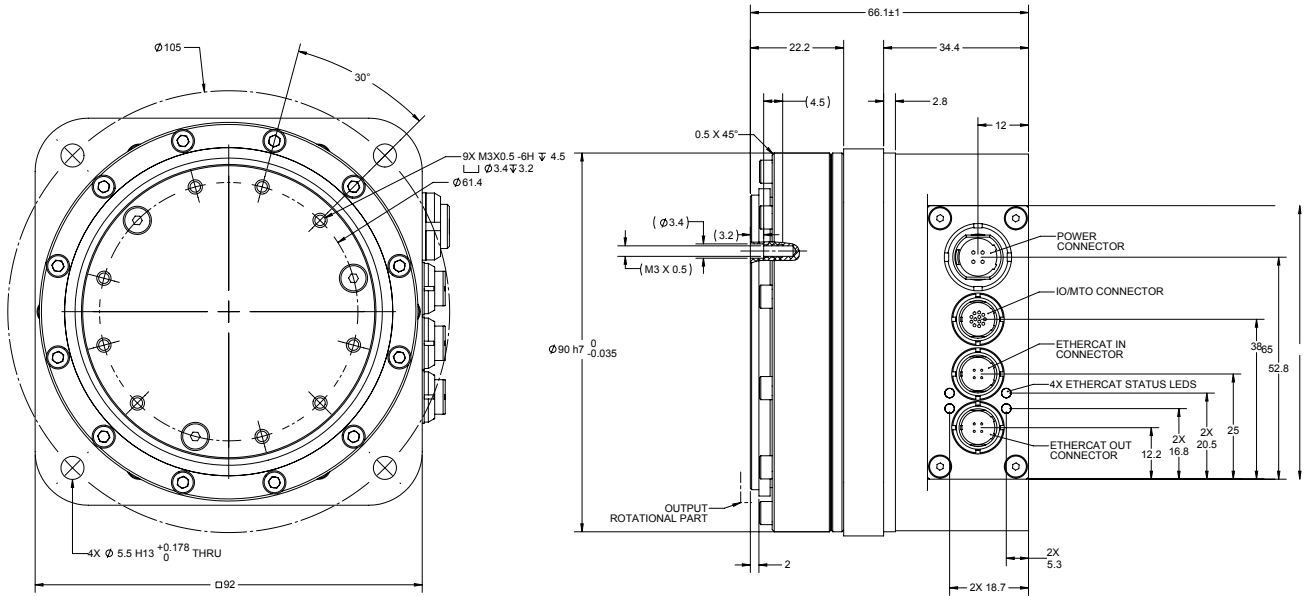
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(Units: mm)



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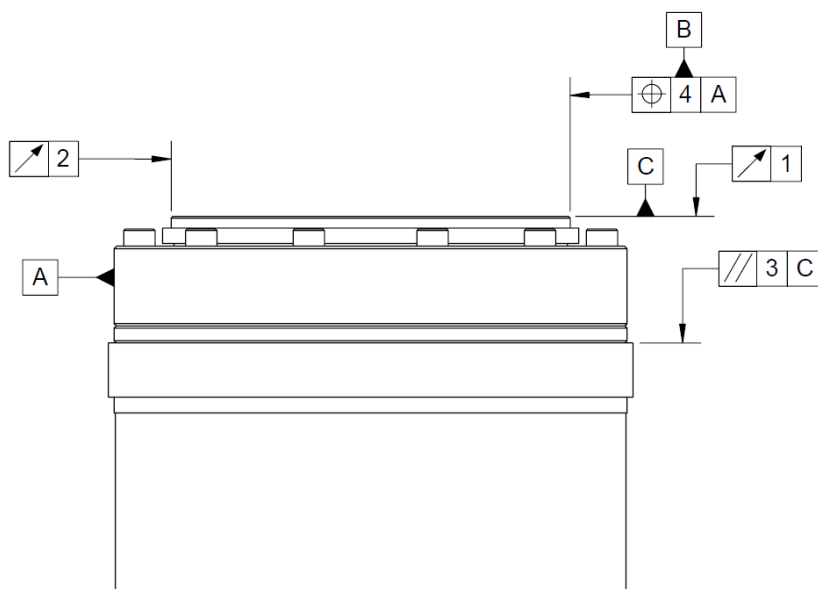
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1-6 Mechanical accuracy

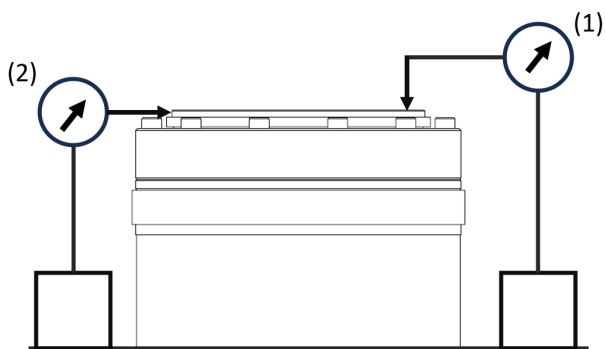
The mechanical accuracies of the output shaft and mounting flange are shown below for LPA series actuators:

Accuracy items	Unit [mm]	
	LPA20	
1. Output shaft surface runout	0.050	
2. Deflection of output shaft	0.040	
3. Parallelism between the output shaft end mounted surface	0.065	
4. True position of output shaft relative to mounting pilot	0.045	



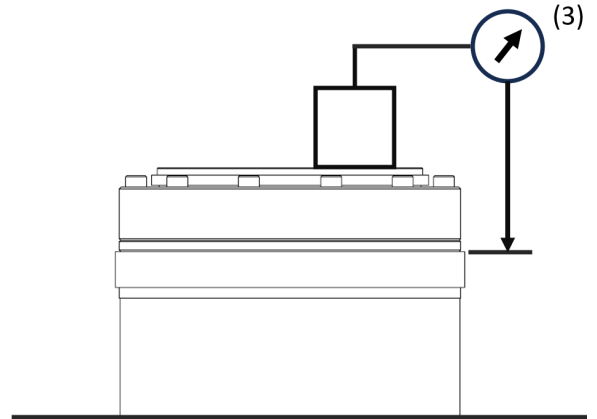
The measuring for the values are as follows:

- 1 Output shaft surface runout**
The indicator on the fixed part measures the axial runout (maximum runout width) of the outermost circumference of output shaft of the output rotary unit per revolution.
- 2 Deflection of output shaft**
The indicator on the fixed part measures the radial runout (maximum runout width) of output shaft of the output rotary unit per revolution.



3 Parallelism between the output shaft and mounted surface

The indicator on the output rotary unit measures the axial runout (maximum runout width) of the outermost circumference of the mounting surface (both on the output shaft side and opposite side) of the output rotary unit per revolution.

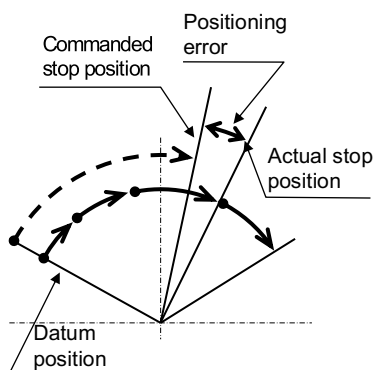


1-7 Positional accuracy

Uni-directional positional accuracy

The uni-directional positional accuracy means the maximum positional difference between the actual rotated angle from the datum position and its theoretical rotational angle in one revolution when series of positioning are performed in the same rotation direction. (Refer to JIS B-6201-1987.)

Since the LPA series incorporates a speed reducer HarmonicDrive® for precision control, the impact of motor shaft positioning error becomes 1/multiple of reduction ratio.



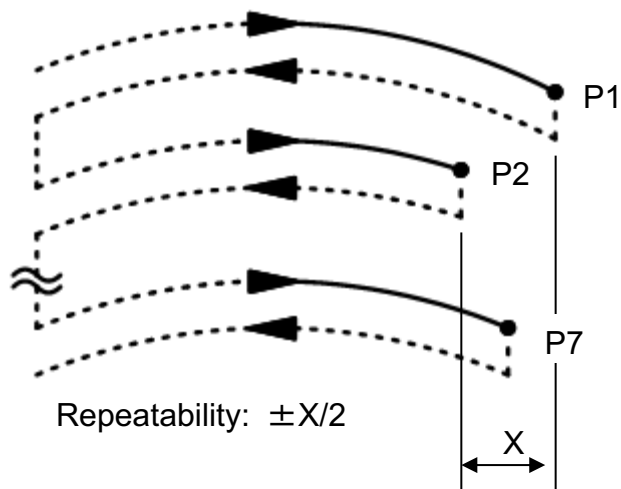
The uni-directional positional accuracy is shown in the table below:

Unit [arc-sec]	
Reduction ratio	Model
1:51	LPA20
1:81	90
1:101	70
	60

Repeatability

For the "repeatability", the output shaft stop position is measured by performing positioning at a position 7 times in the same direction. This measurement is performed at 4 locations on the output shaft and the maximum error is found. The measurement value is expressed as an angle which is 1/2 the maximum error with \pm attached. (JIS B 6201-1987)

Unit [arc-sec]	
Reduction ratio	Model
Ratio to full speed	LPA20
	± 1



*P1 to P7: Stop position
X : Maximum error

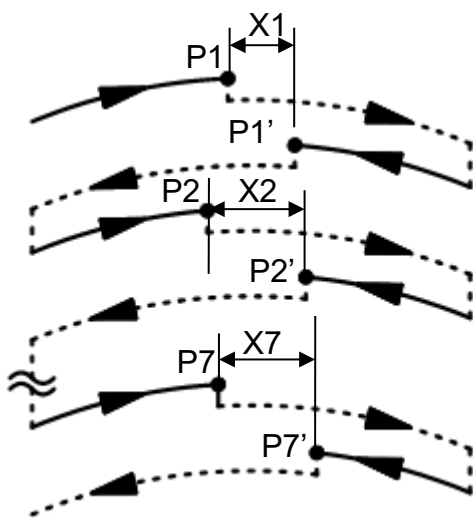
Reverse positional accuracy

For the "reverse positional accuracy", the shaft is rotated beforehand in the forward (or reverse) direction and the stop position for that rotation is set as the reference position. An instruction is given to rotate the shaft in the same direction and from the stopped position, the same instruction is given in the reverse (or forward) direction and the difference between the stop position after this rotation and the reference position is measured.

The average value from repeating this 7 times in each direction is shown and the maximum value measured at the 4 locations on the output shaft is shown. (JIS B 6201-1987)

Unit [arc-sec]

Reduction ratio	Model	LPA20
1:51		110
1:81 or more		35



- *P1 to P7 : Stop position after forward rotation
- P1' to P7' : Stop position after reverse rotation
- X1 to X7 : Difference between the stop positions after forward and reverse rotations

Reverse positional accuracy: $|X1+X2+....+X7|/7$

1-8 Encoder specifications

The dual absolute encoders used in the LPA series are multi-turn magnetic absolute encoders. They consist of a 15 bit multi turn absolute encoder on the motor input and a 14 bit multi turn absolute encoder on the gear output.

Specifications

Type	Dual absolute magnetic
Resolution per motor revolution	15 bits (2^{15} : 32768 pulses)
Resolution per gear revolution	14 bits (2^{14} : 16384 pulses)
Maximum permissible motor shaft rotational speed*1	12000 rpm

*1: This is the rotation speed limit of the encoder and is different from the rotation speed that the motor can drive.

Resolution of output shaft

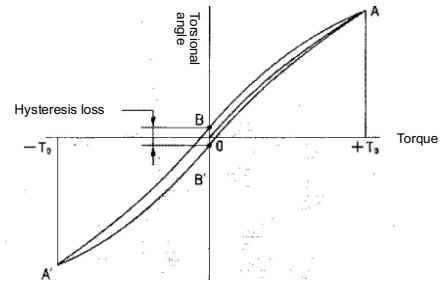
Encoder resolution		15 bits (2^{15} : 32768 pulses)		
Reduction ratio		1:51	1:81	1:101
Resolution of output shaft	Pulse/rev	1671168	2654208	3309568
Resolvable angle per pulse	arc-sec.	Approx. 0.8	Approx. 0.5	Approx 0.4

1-9 Torsional Stiffness

Torsional rigidity

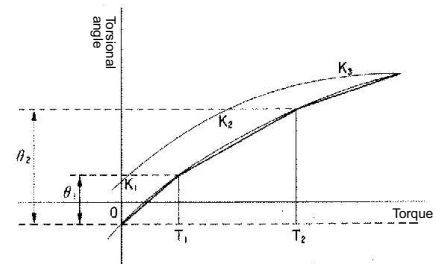
If a torque is applied to the output shaft of the actuator with the servo locked, the output shaft generates a torsional stress roughly in proportion to the torque.

The upper right figure shows the torsional angle of the output shaft when a torque starting from zero and increased to positive side [+T₀] and negative side [-T₀] is applied to the output shaft. This is called [torque vs. torsional angle] diagram, which typically follows a loop 0→A→B→A'→B'→A. The torsional rigidity of LPA series actuator is expressed by the gradient of this [torque vs. torsional angle diagram] representing a spring constant (unit: N·m/rad).



As shown by lower right figure, this [torque vs. torsional angle] diagram is divided into three regions and the spring constants in these regions are expressed by K₁, K₂, and K₃, respectively.

- K₁: Spring constant for torque region 0 to T₁
- K₂: Spring constant for torque region T₁ to T₂
- K₃: Spring constant for torque region over T₂



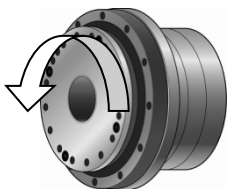
The torsional angle for each region is expressed as follows:

- Range where torque T is T₁ or below: $\varphi = \frac{T}{K_1}$
 - Range where torque T is T₁ to T₂: $\varphi = \theta_1 + \frac{T - T_1}{K_2}$
 - Range where torque T is T₂ to T₃: $\varphi = \theta_2 + \frac{T - T_2}{K_3}$
- * φ : Torsional angle

1-10 Rotation direction

SG type

With the factory settings, the rotation direction is defined as clockwise (CW) as viewed from the output shaft.



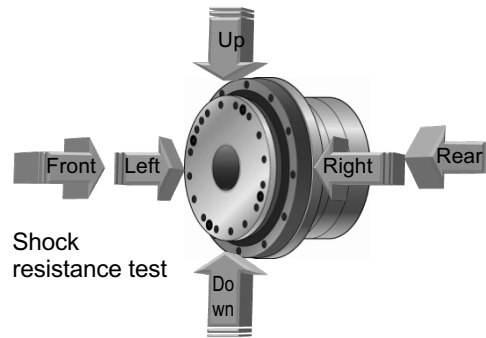
CCW (counterclockwise) rotation direction

1-11 Shock resistance

The shock resistance of the actuator is as follows, and this value is the same in up/down, left/right and front/rear directions:

Impact acceleration: 300 m/s^2

In our shock resistance test, the actuator is tested 3 times in each direction. Actuator operation is not guaranteed in applications where impact exceeding the above value is constantly applied.

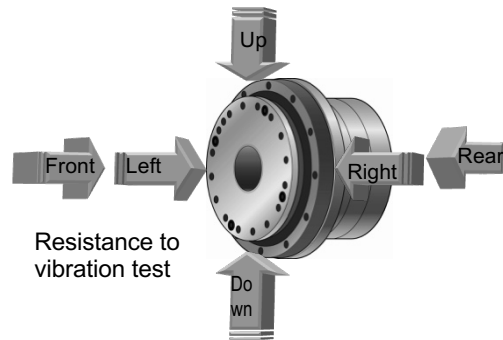


1-12 Resistance to vibration

The resistance to vibration of the actuator is as follows, and this value is the same in up/down, left/right and front/rear directions:

Vibration acceleration: 25 m/s^2 (frequency: 10 to 400 Hz)

In our test, the actuator is tested for 2 hours in each direction at a vibration frequency sweep period of 10 minutes.



1-13 Operable range

The graphs on the next page indicate the operable range for LPA-20 series actuators.

1. Continuous motion range

The range allows continuous operation for the actuator.

2. 50 % duty motion range

This range indicates the torque rotation speed which is operable in the 50 % duty operation (the ratio of operating time and delay time is 50:50).

3. Motion range during acceleration and deceleration

This range indicates the torque rotation speed which is operable momentarily. The range allows instantaneous operation like acceleration and deceleration, usually.

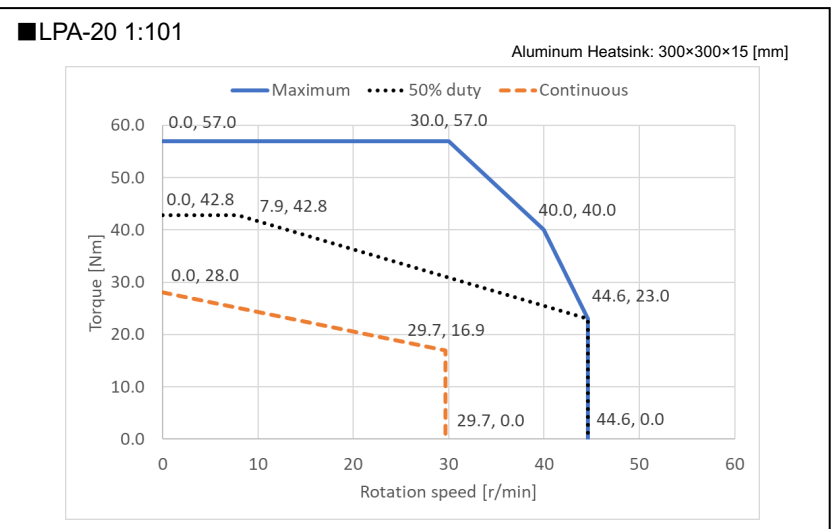
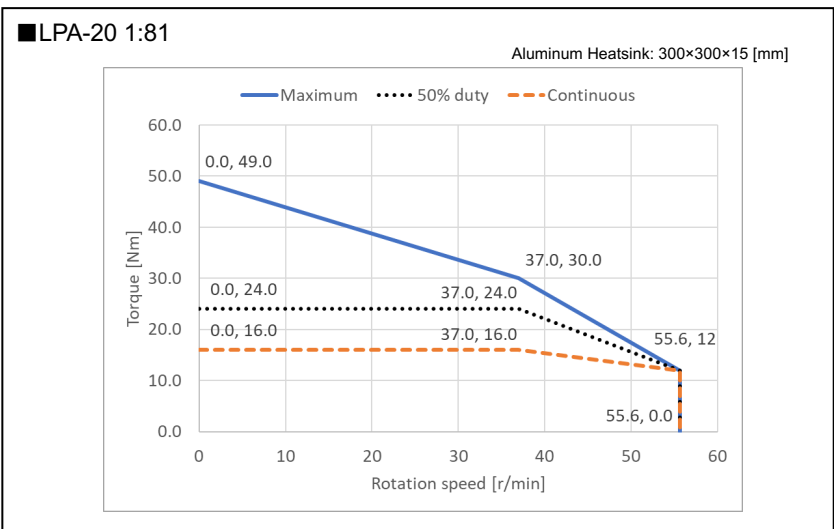
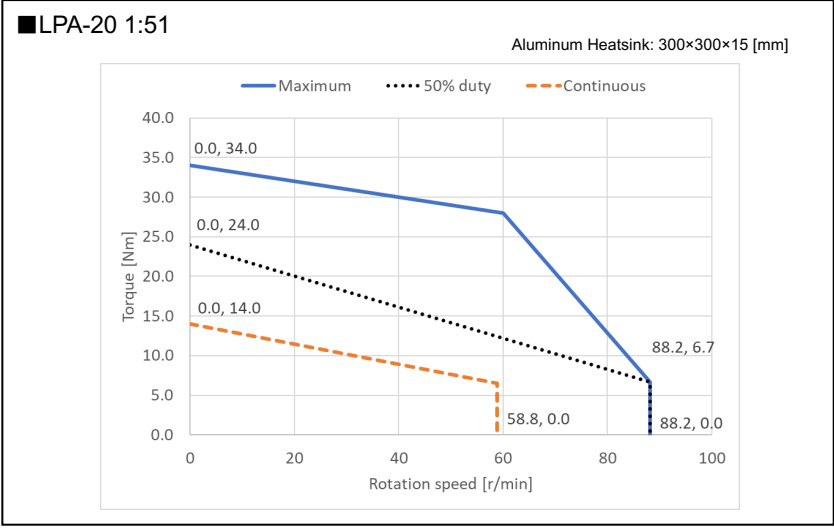
The continuous and 50 % duty motion ranges in each graph are measured on the condition where the radiation plate specified in the graph is installed.

Caution

- When using the product at constant load or in one direction continuously, it may cause lubrication problems. Contact our sales office if the product will be used in this way.
- The continuous motion range and 50 % duty motion range represent allowable ranges where the actuator installed on a specified aluminum radiation plate is operated under natural air cooling. If the radiation area of the mounting member is small or heat conduction of the material is poor, adjust the operating conditions to keep the rise in the actuator's ambient temperature to 40 K or less as a guide.

1

Outlines

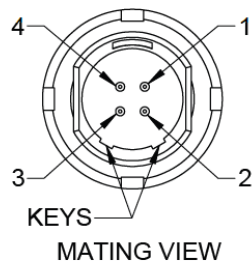


1-14 Connector specifications

The following tables show specifications of the motor and encoder cables of LPA series actuators.

Power and communication cable

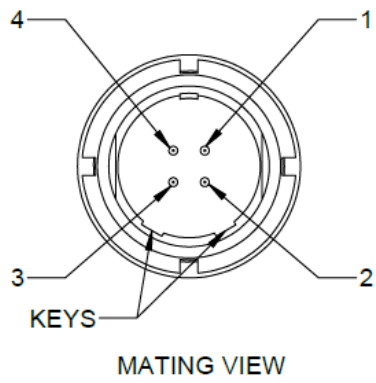
Connector pin layout



POWER/COMMUNICATION CONNECTOR LEMO EEL.1T.304.CYC	
PIN	SIGNAL
1	+48VDC
2	CANH
3	CANL
4	0VDC

EtherCAT® communication cable

Connector pin layout:

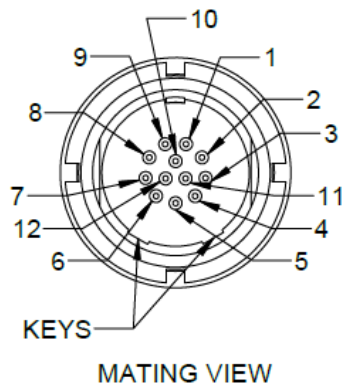


ETHERCAT IN/OUT CONNECTOR LEMO EEL.0T.304.CYC	
PIN	SIGNAL
1	TX+
2	TX-
3	RX+
4	RX-

IO/MTO cable

Description: CBL-EZZ-L012-N

Connector pin layout:



MTO/IO CONNECTOR LEMO EEL.0T.312.CLA	
PIN	SIGNAL
1	ISOLATED GROUND*
2	INPUT 4*
3	INPUT 3*
4	INPUT/OUTPUT 2
5	INPUT/OUTPUT 1
6	0VDC
7	0VDC
8	MTO2-
9	MTO2+
10	MTO1-
11	MTO1+
12	+24V**

* OPTO-ISOLATED INPUT 3 AND 4
RETURN PATH

** THIS IS A VOLTAGE OUTPUT, DO
NOT APPLY VOLTAGE TO THIS PIN

Chapter 2

Selection guidelines

This chapter explains how to select a proper LPA series actuator.

2-2	Change in load inertia moment	2-1
2-3	Verifying and examining load weights	2-2
2-4	Verifying operating conditions	2-6

2-1 Change in load inertia moment

2

For LPA series combined with the high reduction ratio of HarmonicDrive®, the effects of change in load inertia moment on the servo performance are minimal. In comparison to direct servo drive mechanisms, therefore, this benefit allows the load to be driven with a better servo response.

For example, assume that the load inertia moment increases to N-times. The total inertia moment converted to motor shaft which has an effect on servo response is as follows:

The symbols in the formulas are:

J_S : Total inertia moment converted to motor shaft

J_M : Inertia moment of motor

R : Reduction ratio of LPA series actuator

L : Ratio of load inertia moment to inertia moment of motor

N : Rate of change in load inertia moment

- Direct drive

$$\text{Before: } J_S = J_M(1+L) \quad \text{After: } J_{S'} = J_M(1+NL) \quad \text{Ratio: } J_{S'}/J_S = \frac{1+NL}{1+L}$$

- Driven by LPA series

$$\text{Before: } J_S = J_M \left(1 + \frac{L}{R^2} \right) \quad \text{After: } J_{S'} = J_M \left(1 + \frac{NL}{R^2} \right) \quad \text{Ratio: } J_{S'}/J_S = \frac{1+NL/R^2}{1+L/R^2}$$

With LPA series, the value of R increases from 51 to 101, which means that the value increases substantially from $R^2 = 2,601$ to $R^2 = 10,201$. Then the ratio is $J_{S'}/J_S \approx 1$. This means that LPA drive systems are hardly affected by the load variation.

Therefore, it is not necessary to take change in load inertia moment into consideration when selecting LPA series actuator or setting up the initial servo amplifier parameters.

Caution

- When a load generating a large inertia moment is operated frequently, a greater regenerative energy will be produced during braking. If the regenerative energy produced exceeds the absorption capacity of the built-in regenerative resistor of the integrated servo amplifier, an additional regenerative resistor must be connected externally.

2-2 Verifying and examining load weights

The LPA series actuator incorporates a precise cross roller bearing for directly supporting an external load (output flange). To demonstrate the full ability of the actuator, verify the maximum load moment load as well as the life and static safety coefficient of the cross roller bearing.

Checking procedure

1 Verifying the maximum load moment load (M_{max})

Calculating the maximum load moment load (M_{max})



Verifying the maximum load moment load (M_{max}) is less than or equal to the permissible moment load (M_c)

2 Verifying life

Calculate the average radial load (F_{rav}) and average axial load (F_{aav}).



Calculate the radial load coefficient (X) and the axial load coefficient (Y).



Calculate the life of the bearing and verify the life is allowable.

3 Verifying the static safety coefficient

Calculate the static equivalent radial load (P_o).



Verify the static safety coefficient (f_s).

Specifications of the main roller bearing

The following table shows the specifications of the main roller bearings built in LPA actuators.

Table 1: Specifications of the main roller bearings

Model \ Item	Circular pitch of the roller (dp)	Offset amount (R)	Basic dynamic rated load (C)	Basic static rated load (C ₀)	Permissible moment load (M _c)	Moment stiffness (K _m)
	mm	mm	kN	kN	N·m	×10 ⁴ N·m/rad
LPA20	70	14.2	7.3	11.0	93	21

Maximum load moment load

The formula below shows how to calculate the maximum load moment load (M_{max}). Verify that the maximum load moment load (M_{max}) is less than or equal to the permissible moment load (M_c).

◆ **Formula (1): Maximum load moment load**

$$Fr_{av} = \sqrt[10/3]{\frac{n_1 t_1 |Fr_1|^{10/3} + n_2 t_2 |Fr_2|^{10/3} + \dots + n_n t_n |Fr_n|^{10/3}}{n_1 t_1 + n_2 t_2 + \dots + n_n t_n}}$$

Symbols used in the formula

M_{max}	Maximum load moment load	N · m	
Fr_{max}	Max. radial load	N	Refer to Fig.1.
Fa_{max}	Max. axial load	N	Refer to Fig.1.
L_r, La		mm	Refer to Fig.1.

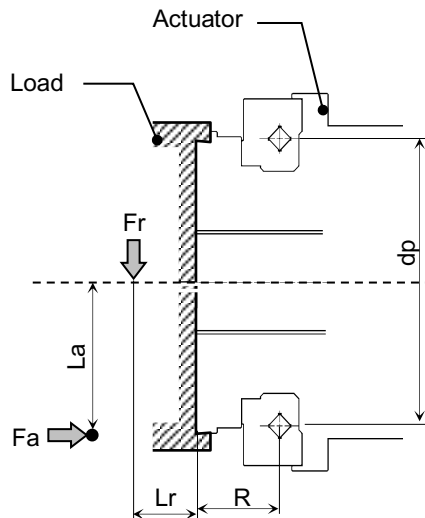


Fig. 1: External load action

Verifying life

Calculating average loads (average radial and axial loads, average output rotational speed)

When the radial and/or axial loads vary during motion, calculate and verify the life of the cross roller bearing converting the loads to their average values.

◆ **Formula (2): Average radial load (Fr_{av})**

$$Fr_{av} = \sqrt[10/3]{\frac{n_1 t_1 |Fr_1|^{10/3} + n_2 t_2 |Fr_2|^{10/3} + \dots + n_n t_n |Fr_n|^{10/3}}{n_1 t_1 + n_2 t_2 + \dots + n_n t_n}}$$

The maximum radial load in section t_1 is given by Fr_1 , while the maximum radial load in section t_3 is given by Fr_3 .

◆ **Formula (3): Average axial load (Fa_{av})**

$$Na_{av} = \frac{n_1 t_1 + n_2 t_2 + \dots + n_n t_n}{t_1 + t_2 + \dots + t_n}$$

The maximum axial load in section t_1 is given by Fa_1 , while the maximum axial load in section t_3 is given by Fa_3 .

◆ **Formula (4): Average output rotational speed (Nav)**

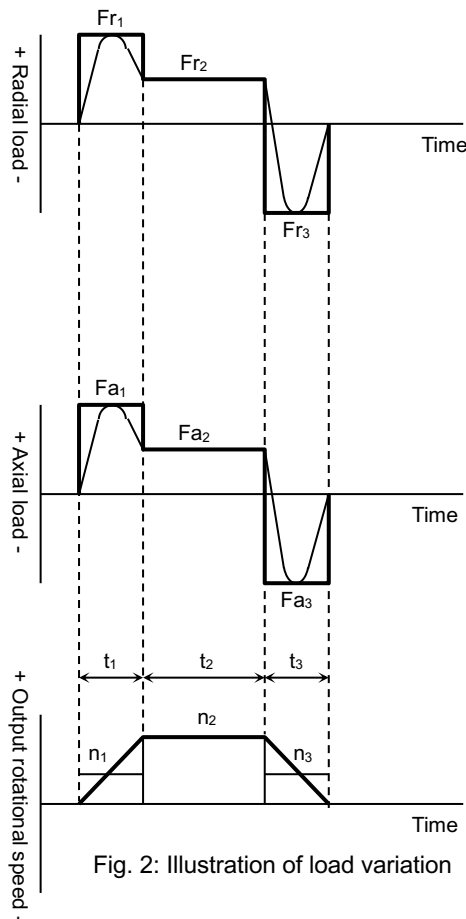
$$P_c = X \cdot \left(Fr_{av} + \frac{2(Fr_{av}(L_r + R) + Fa_{av} \cdot La)}{dp} \right) + Y$$


Fig. 2: Illustration of load variation

Radial load coefficient and axial load coefficient

Determine the values of radial load coefficient (X) and axial load coefficient (Y) based on conditional judgment according to formula (5).

Table 2: Radial load coefficient (X), axial load coefficient (Y)

◆ Formula (5)	X	Y
$\frac{Fa_{av}}{Fr_{av} + 2(Fr_{av}(L_r + R) + Fa_{av} \cdot La)/dp} \leq 1.5$	1	0.45
$\frac{Fa_{av}}{Fr_{av} + 2(Fr_{av}(L_r + R) + Fa_{av} \cdot La)/dp} > 1.5$	0.67	0.67

Symbols used in the formulas

Fr_{av}	Average radial load	N	Refer to the average load.
Fa_{av}	Average axial load	N	Refer to the average load.
L_r, La	—	mm	Refer to Fig.1.
R	Offset amount	mm	Refer to Fig.1 and Table 1.
dp	Pitch circle diameter of a roller	mm	Refer to Fig.1 and Table 1.

Dynamic equivalent radial load

◆ Formula (6): Dynamic equivalent radial load

$$L_{B-10} = \frac{10^6}{60 \times N_{av}} \times \left(\frac{C}{f_w \cdot P_c} \right)^{10/3}$$

Symbols used in the formulas

P_c	Dynamic equivalent radial load	N	
Fr_{av}	Average radial load	N	Obtained by formula (2).
Fa_{av}	Average axial load	N	Obtained by formula (3).
dp	Pitch circle diameter of a roller	mm	Refer to Table 1.
X	Radial load coefficient	—	Refer to Table 2.
Y	Axial load coefficient	—	Refer to Table 2.
L_r, La	—	mm	Refer to Fig.1.
R	Offset amount	mm	Refer to Fig.1 and Table 1.

Life of cross roller bearing

Calculate the life of cross roller bearing with the formula (7):

◆ Formula (7): Cross roller bearing life

$$L_{oc} = \frac{10^6}{60 \times n_1} \times \frac{90}{\theta} \times \left(\frac{C}{f_w \cdot P_c} \right)^{10/3}$$

Symbols used in the formulas

L_{B-10}	Life	hour	—
N_{av}	Average output rotational speed	r/min	Obtained by formula (4).
C	Basic dynamic rated load	N	Refer to Table 1.
P_c	Dynamic equivalent radial load	N	Obtained by formula (6).
f_w	Load coefficient	—	Refer to Table 3.

Table 3: Load coefficient

Loaded state	f_w
Smooth operation free from impact/vibration	1 to 1.2
Normal operation	1.2 to 1.5
Operation subject to impact/vibration	1.5 to 3

Cross roller bearing life based on oscillating movement

Use formula (8) to calculate the cross roller bearing life against oscillating movement.

◆ **Formula (8): Cross roller bearing life (oscillating)**

$$P_o = F_{rmax} + \frac{2M_{max}}{d_p} + 0.44F_{amax}$$

Symbols used in the formulas

Loc	Life	hour	—
n_1	Number of reciprocating oscillation per min.	cpm	—
C	Basic dynamic rated load	N	Refer to Table 1.
P_c	Dynamic equivalent radial load	N	Obtained by formula (6).
f_w	Load coefficient	—	Refer to Table 3.
θ	Oscillating angle/2	—	Refer to Fig.3.

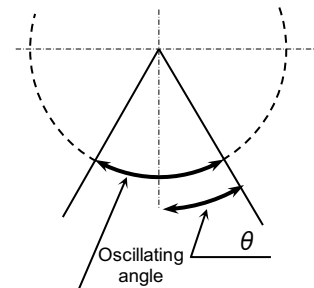


Fig. 3: Oscillating movement

If the oscillating angle is 5° or less, fretting wear may occur because oil film does not form effectively on the contact surface between the race and rolling element of the cross roller bearing. In such cases, consult HDLLC.

Verifying static safety coefficients

Static equivalent radial load

◆ **Formula (9): Static equivalent radial load**

$$f_s = \frac{C_o}{P_o}$$

Symbols used in the formulas

F_{rmax}	Max. radial load	N	Refer to Fig.1.
F_{amax}	Max. axial load	N	Refer to Fig.1.
M_{max}	Max. moment load	N·m	Refer to the maximum load weight calculation methods.
d_p	Pitch circle diameter of a roller	mm	Refer to Table 1.

Static safety coefficient

Generally, the static equivalent load is limited by the basic static rated load (C_o). However, the specific limit should be calculated according to the using conditions and required conditions. In this case, calculate the static safety coefficient (f_s) by formula (10).

Table 4 shows general values representing using conditions. Calculate the static equivalent radial load (P_o) by formula (9).

◆ **Formula (10): Static safety coefficient**

$$f_s = \frac{C_o}{P_o}$$

Symbols used in the formulas

f_s	Static safety coefficient	—	Refer to Table 4.
C_o	Basic static rated load	N	Refer to Table 1.
P_o	Static equivalent radial load	N	Obtained by formula (9).

Table 4: Static safety coefficients

Using conditions	f_s
High rotational accuracy is required, etc.	≥ 3
Operation subject to impact/vibration	≥ 2
Normal operation	≥ 1.5

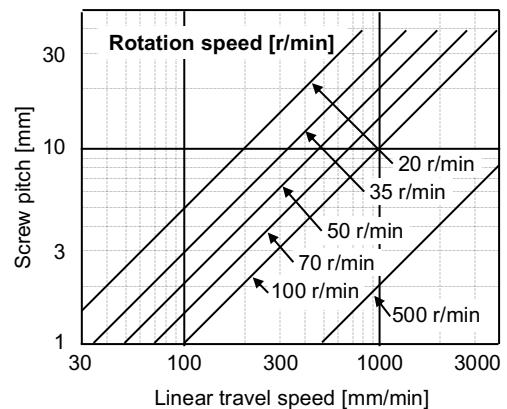
2-3 Verifying operating conditions

The actuator generates heat if started/stopped repeatedly or operated continuously at high speed. Accordingly, examine whether or not the generated heat can be accommodated. The study is as follows:

Examining actuator rotation speed

Calculate the actuator rotation speed [r/min] of the load driven by LPA series. For linear operation, use the rotation speed conversion formula below:

$$\text{Actuator rotational speed [r/min]} = \frac{\text{Linear travel speed [mm/min]}}{\text{Screw feed pitch [mm]}}$$



Select an appropriate reduction ratio from 51, 81, and 101 so that the calculated actuator rotation speed does not exceed the maximum rotational speed of LPA series actuator.

Calculating and examining load inertia moment

Calculate the load inertia moment of the load driven by LPA series actuator. Refer to [A-2 Calculating inertia moment] (PA-9) for the calculation.

Load torque calculation

Calculate the load torque as follows:

- Rotary motion

The rotary torque for the rotating mass W on the ring of radius r from the center of rotation is shown in the figure to the right.

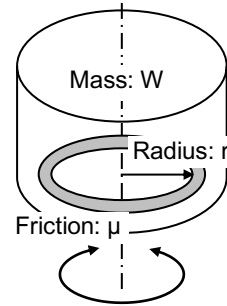
$$T = 9.8 \times \mu \times W \times r$$

T : Rotary torque [N·m]

μ : Friction coefficient

W : Mass [kg]

r : Average radius of friction side [m]



- Linear operation (horizontal operation)

The rotary torque when the mass W moves horizontally due to the screw of pitch P is shown below.

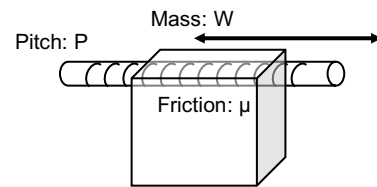
$$T = 9.8 \times \mu \times W \times \frac{P}{2 \times \pi}$$

T : Rotary torque [N·m]

μ : Friction coefficient

W : Mass [kg]

P : Screw feed pitch [m]



- Linear operation (vertical operation)

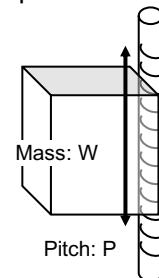
The rotary torque when the mass W moves vertically due to the screw of pitch P is shown below.

$$T = 9.8 \times W \times \frac{P}{2 \times \pi}$$

T : Rotary torque [N·m]

W : Mass [kg]

P : Screw feed pitch [m]



Acceleration time and deceleration time

Calculate acceleration and deceleration times for the selected actuator.

$$\text{Acceleration time: } t_a = k \times (J_A + J_L) \times \frac{2 \times \pi}{60} \times \frac{N}{T_M - T_L}$$

$$\text{Deceleration time: } t_d = k \times (J_A + J_L) \times \frac{2 \times \pi}{60} \times \frac{N}{T_M + 2 \times T_F + T_L}$$

t_a : Acceleration time [s]

t_d : Deceleration time [s]

k : Acceleration reduction coefficient 1 to 1.5
The total positioning time may become shorter if the acceleration is lowered for the purpose of reducing the settling time after positioning.

J_A : Actuator inertia moment [kg·m²]

J_L : Load inertia moment [kg·m²]

N : Actuator rotation speed [r/min]

T_M : Maximum actuator torque [N·m]

T_F : Actuator friction torque [N·m]

$$T_F = K_T \times I_R - T_R$$

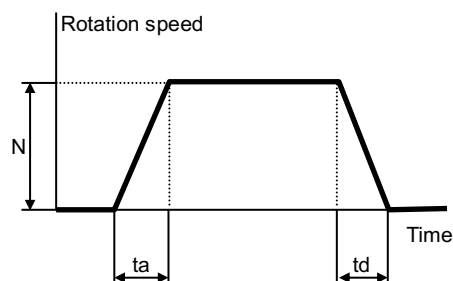
K_T : Torque constant [N·m/A]

T_R : Allowable continuous torque [N·m]

I_R : Allowable continuous current [A]

T_L : Load torque [N·m]

The polarity is positive (+) when the torque is applied in the rotation direction, or negative (-) when it is applied in the opposite direction.



● Calculation example 1

Select an actuator that best suits the following operating conditions:

- Rotation speed: 80 [r/min]
- Load inertia moment: 1.5 [kg·m²]
- Since the load mechanism is mainly inertia, the load torque is negligibly small.

(1) After applying these conditions to the graph in [2-1], SHA25P51SG-B09A200 is tentatively selected.

(2) From the rated table, the following values are obtained:

$$J_A = 0.56 \text{ [kg·m}^2\text{]}$$

$$T_M = 127 \text{ [N·m]}$$

$$T_R = 41 \text{ [N·m]}$$

$$K_T = 19 \text{ [N·m/A]}$$

$$I_R = 3 \text{ [A]}$$

(3) Based on the above formula, the actuator's friction torque T_F is calculated as

$$19 \times 3 - 41 = 16 \text{ [N·m].}$$

(4) If $k = 1.3$, the acceleration time and deceleration time can be obtained as follows from the above formulas:

$$t_a = 1.3 \times (0.56 + 1.5) \times 2 \times \pi / 60 \times 80 / 127 = 0.177 \text{ [s]}$$

$$t_d = 1.3 \times (0.56 + 1.5) \times 2 \times \pi / 60 \times 80 / (127 + 2 \times 16) = 0.141 \text{ [s]}$$

(5) If the calculated acceleration/deceleration times are too long, correct the situation by:

- Reducing load inertia moment
- Selecting an actuator with a larger frame size

Examining effective torque and average rotation speed

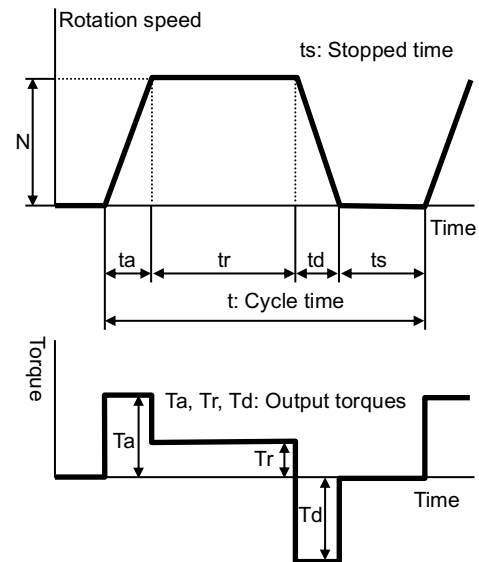
One way to check if the heat generated from the actuator during operation would present a problem is to determine if the point of operation, determined by the effective torque and average rotation speed, is inside the continuous motion range explained in [1-14 Operable range] (page 1-26).

Using the following formula, calculate the effective torque T_m and average rotation speed N_{av} when the actuator is operated repeatedly in the drive pattern shown to the right.

$$T_m = \sqrt{\frac{T_a^2 \times t_a + T_r^2 \times t_r + T_d^2 \times t_d}{t}}$$

$$N_{av} = \frac{N/2 \times t_a + N \times t_r + N/2 \times t_d}{t}$$

t_a	: Acceleration time from speed 0 to N	[s]
t_d	: Deceleration time from speed N to 0	[s]
t_r	: Operation time at constant speed N	[s]
t	: Cycle time	[s]
T_m	: Effective torque	[N·m]
T_a	: Torque during acceleration	[N·m]
T_r	: Torque at constant speed	[N·m]
T_d	: Torque during deceleration	[N·m]
N_{av}	: Average rotation speed	[r/min]
N	: Rotation speed at constant speed	[r/min]



● Calculation example 2

An example of SHA25P51SG-B09A200 is explained.

Operating conditions: Accelerate an inertia load and then let it move at a constant speed, followed by deceleration, based on conditions similar to those used in calculation example 1. The travel angle per cycle is 120° and the cycle time is 1 second.

(1) The travel angle is calculated from the area of the rotation speed vs. time diagram shown above. In other words, the travel angle θ is calculated as follows:

$$\theta = (N / 60) \times \{t_r + (t_a + t_d) / 2\} \times 360$$

$$\text{Accordingly, } t_r = \theta / (6 \times N) - (t_a + t_d) / 2$$

When $\theta = 120^\circ$, and

$$t_a = 0.177 \text{ [s]}$$

$$t_d = 0.141 \text{ [s]}$$

$$N = 80 \text{ [r/min]}$$

in calculation example 1, are applied to this formula, t_r is calculated as 0.091 second.

(2) Next, calculate the torque during acceleration and torque during deceleration. Based on the acceleration/deceleration time formulas in the preceding section, the relational expressions for torque during acceleration and torque during deceleration if $k = 1$ are as follows:

$$T_a = (J_A + J_L) \times 2 \times \pi / 60 \times N / t_a + T_L$$

$$T_d = (J_A + J_L) \times 2 \times \pi / 60 \times N / t_d - 2 \times T_F - T_L$$

When the values in calculation example 1 are applied to this formula,

$$T_a = 98 \text{ [N·m]} \text{ and}$$

$$T_d = 90 \text{ [N·m]}$$

are obtained.

(3) Calculate the effective torque. Apply the values in (1) and (2), and $T_r = 0 \text{ N·m}$ and $t = 1$ second, to the above formulas.

$$T_m = \sqrt{\frac{98^2 \times 0.177 + 0^2 \times 0.091 + 90^2 \times 0.141}{1}} = 53 \text{ [N·m]}$$

(4) Calculate the average rotation speed. Apply the values in (1), and $N = 80 \text{ r/min}$ and $t = 1$

second, to the above formulas.

$$N_{av} = \frac{80/2 \times 0.177 + 80 \times 0.091 + 80/2 \times 0.141}{1} = 20 \text{ [r/min]}$$

(5) The figure on the right shows the points of operation determined by the effective torque and average rotation speed calculated above, plotted on the graph of operable range of SHA25P51SG, exceeding the continuous motion range. The conclusion is that this actuator cannot be operated continuously under these conditions. Accordingly,

- ◆ the operation pattern
- ◆ load (possible reduction)
- ◆ actuator size No.

etc., must be reexamined.

The following formula is a modified version of the formula for effective torque. By applying the value of allowable continuous torque to T_m in this formula, the allowable cycle time can be calculated.

$$t = \frac{T_a^2 \times t_a + T_r^2 \times t_r + T_d^2 \times t_d}{T_m^2}$$

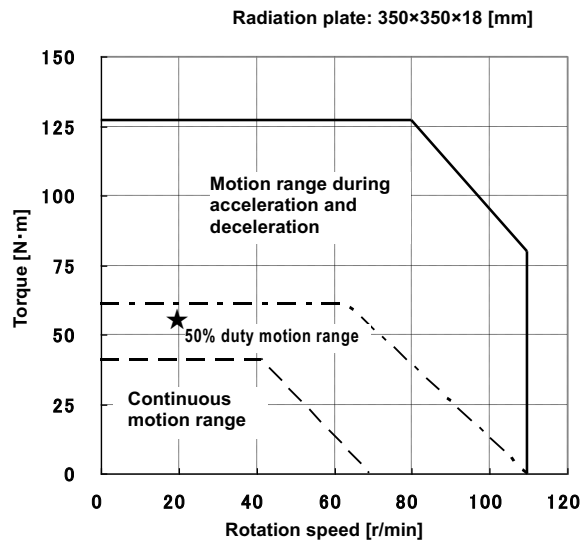
Apply the following:

- $T_a = 98 \text{ [N}\cdot\text{m]}$
- $T_r = 0 \text{ [N}\cdot\text{m]}$
- $T_d = 90 \text{ [N}\cdot\text{m]}$
- $T_m = 41 \text{ [N}\cdot\text{m]}$
- $t_a = 0.177 \text{ [s]}$
- $t_r = 0.091 \text{ [s]}$
- $t_d = 0.141 \text{ [s]}$

Then, the following equation is obtained:

$$t = \frac{98^2 \times 0.177 + 90^2 \times 0.141}{41^2} = 1.69 \text{ [s]}$$

Based on the result, setting the cycle time to 1.7 seconds or more to provide a longer stopped time gives $T_m = 41 \text{ N}\cdot\text{m}$ or less, thereby permitting continuous operation within the allowable continuous torque.



Operable range of SHA25P51SG

Caution

- The aforementioned continuous motion range represents an allowable range where the actuator installed on a specified aluminum radiation plate is operated under natural air cooling. If the radiation area of the mounting member is small or heat conduction of the material is poor, adjust the operating conditions to keep the rise in the actuator's ambient temperature to 40 K or less as a guide.

Chapter 3

Installing LPA

The following explains the installation procedures of the actuators.

3-1	Product Verification	3-1
3-2	Notices on handling	3-2
3-3	Location and installation	3-4

3-1 Product Verification

Check the following items after unpacking the package.

Verification steps

1 Check the items thoroughly for damage sustained during transportation.

If any item is damaged, immediately contact the dealer.

2 Check if the actuator is what you ordered.

Verify the description laser marking. Refer to the section [1-2 Model] (page 1-2) in this manual for the detail of the model codes.

4 Check if the input voltage being input are correct.

The value of the power voltage input is shown in the “INPUT” field of the actuator laser mark. If the voltage to be supplied is different from the label voltage, immediately contact the dealer it was purchased from.



Do not connect a supply voltage other than the voltage specified on the servo amplifier’s nameplate.

Connecting a power supply not matching the input voltage specified on the nameplate may result in damage to the servo amplifier, injury or fire.

3-2 Notices on handling

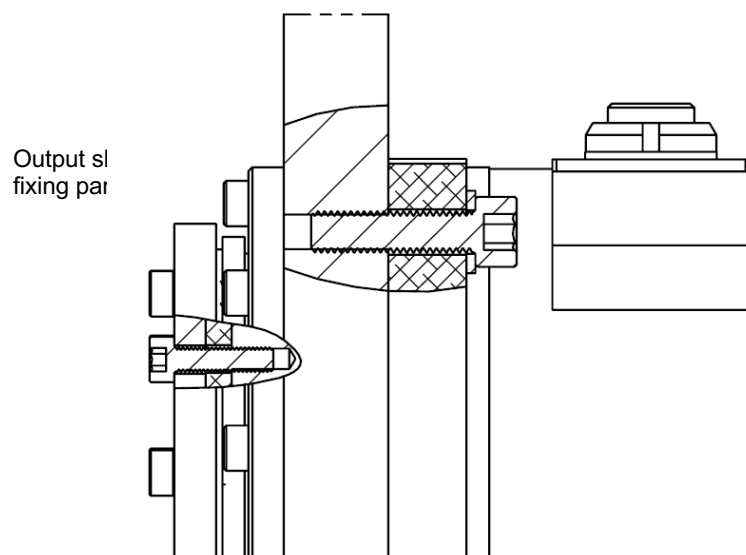
Handle LPA series actuator carefully by observing the notices specified below.



- (1) Do not apply any excessive force or impact, especially to the actuator's output shaft.
- (2) Do not put the LPA series actuator on a table, shelf, etc., where the actuator could easily fall.
- (3) Do not connect the actuator terminals directly to the power supply. The actuator may burn and cause fire or electric shock.
- (4) The allowable storage temperature is -20 to $+60$ °C. Do not expose the actuator to direct sunlight for long periods of time or store it in areas in low or high temperature.
- (5) The allowable relative storage humidity is 80 % or less. Do not store the actuator in a very humid place or in areas where temperatures are likely to fluctuate greatly during day and night.
- (6) Do not use or store the actuator in locations subject to flammable or corrosive gases or dust particles.
- (7) Handle your actuator with due care by wearing safety shoes or take other proper precaution.

Installation and transmission torque

Example of actuator assembly are shown below. Use high-tension bolts and tighten them with a torque wrench to control the tightening torque. Use flat washers because the tightening torque is high and the actuator flange is made of aluminum.



Assembly example 2

Recommended tightening torque and transmission torque

Item \ Model		LPA20	
		Output shaft	Actuator
Number of bolts, size		9-M3	4-M5
Bolt installation P.C.D.	mm	61.4	105.0
	Tightening torque		
	N·m	2	6.4
	in·lbf	17.7	57
Transmission torque	N·m	115	168
	in·lbf	1018	1487

Note 1) The female thread material is premised to withstand the bolt tightening torque.

2) Recommended bolt: Hexagonal bolt per JIS B 1176 Intensity category: JIS B 1051 12.9 or higher

3) Calculation conditions Torque efficiency: 0.2 Tightening efficiency: 1.4 Tightening friction coefficient: 0.15

Precautions on installation

When designing the assembly, take note that application of any abnormal or excessive force that causes deformation of the installation surface may result in performance drop. To demonstrate the excellent performance of LPA series actuator fully, take note of the following points:

- Warp and deformation on the mounting surface
- Blocking of foreign matter
- Burrs, rising and abnormal position accuracy around tapped mounting holes
- Insufficient chamfering of mounting faucet joint
- Abnormal circularity of mounting faucet joint

Surface treatments

Standard LPA series actuators are given the following surface treatments:

Location	Surface treatments
Housing	No treatment (aluminum material is exposed)
Screws (gear head)	Black oxide coating treatment
Screw (IO plate / rear cover)	No treatment
Output bearing	Raydent treatment

The surface treatments given to LPA series actuators do not fully prevent rust

3-3 Location and installation

Installing environment

The environmental conditions of the installation location for LPA series actuators must be as follows. Determine an appropriate installation location by observing these conditions without fail.

- ◆ Operating temperature: 0 to 40 °C
The temperature in the cabinet may be higher than the atmosphere depending on the power loss of housed devices and size of the cabinet. Plan the cabinet size, cooling system, and device locations so the ambient temperature of the actuator is kept 40 °C or below.
- ◆ Operating humidity: Relative humidity of 20 to 80 %.
Make sure no condensation occurs. Take note that condensation is likely to occur in a place where there is a large temperature change between day and night or when the actuator is started/stopped frequently.
- ◆ Vibration: 25 m/s² (10 to 400 Hz) or less (Refer to [0 Resistance to vibration] (P1-25).)
- ◆ Impact: 300 m/s² or less (Refer to [0 Shock resistance] (page 1-24).)
- ◆ Use environment: Free from condensation, metal powder, corrosive gases, water, oil mist, flammable gases, etc.
- ◆ Protection class: Standard products are structurally designed to meet the IP-54 requirements.

The protection class against water entry is as follows:
4: Protected against water splashed from all directions.

The protection class against contact and entry of foreign matter is as follows:
5: Protected against entry of dust/dirt. Entry of water or foreign matter caused by incomplete protection must not affect the operation of the system.

However, rotating and sliding areas (oil seal areas) and connectors of LPA are not IP-54-compliant. Connectors are IP 68 compliant.

- ◆ Locate the driver indoors or within an enclosure. Do not expose it to the sunlight.
- ◆ Altitude: lower than 1000 m above sea level
- ◆ The oil seals in rotating and sliding areas do not fully prevent leakage of lubricant. If the actuator is used in a clean room, etc., provide additional oil leakage prevention measures.

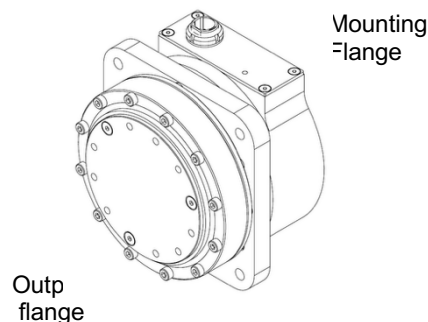
Installation

The LPA series actuator drives mechanical load system at high accuracy. When installing the actuator, pay attention to precision and do not tap the actuator output part with a hammer, etc. The actuator houses an encoder. Excessive impact may damage the encoder.

Installation procedure

1 Align the axis of rotation of the actuator and the load mechanism precisely.

Note 1: Perform this alignment carefully, especially when a rigid coupling is used. Even slight misalignment may cause the permissible load of the actuator to be exceeded, resulting in damage to the output shaft.



2 Connect power and communication cable(s).

A single power and communication cable is provided for CANopen® options, while separate power and communication cables are provided for EtherCAT® options. Mating cables are sold separately.

Caution

- Do not bring strong magnetic bodies (magnet chucks, permanent magnets, etc.) near the rear cover of the actuator. Encoder abnormality may result.
- This encoder requires an external power supply to retain absolute positions.



Do not disassemble/reassemble the actuator.

The actuator uses many precision parts. If the actuator is disassembled/reassembled by the customer, it may cause burned damage or uncontrollable operation of the actuator, resulting in fire or injury.

Appendix

A-1 Unit conversion	A-7
A-2 Calculating inertia moment	A-9

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Appendix

A-1 Unit conversion

This manual employs SI system for units. Conversion factors between the SI system and other systems are as follows:

(1) Length

SI system	m	
↓		
Unit	ft.	in.
Factor	3.281	39.37

(2) Linear speed

SI system	m/s			
↓				
Unit	m/min	ft./min	ft./s	in/s
Factor	60	196.9	3.281	39.37

(3) Linear acceleration

SI system	m/s ²			
↓				
Unit	m/min ²	ft./min ²	ft./s ²	in/s ²
Factor	3600	1.18x10 ⁴	3.281	39.37

(4) Force

SI system	N		
↓			
Unit	kgf	lb (force)	oz (force)
Factor	0.102	0.225	4.386

(5) Mass

SI system	kg	
↓		
Unit	lb.	oz.
Factor	2.205	35.27

(6) Angle

SI system	rad		
↓			
Unit	deg.	min.	sec.
Factor	57.3	3.44x10 ³	2.06x10 ⁵

(7) Angular speed

SI system	rad/s			
↓				
Unit	deg/s	deg/min	r/s	r/min
Factor	57.3	3.44x10 ³	0.1592	9.55

Unit	ft.	in.
Factor	0.3048	0.0254
↓		
SI system	m	

Unit	m/min	ft./min	ft./s	in/s
Factor	0.0167	5.08x10 ⁻³	0.3048	0.0254
↓				
SI system	m/s			

Unit	m/min ²	ft./min ²	ft./s ²	in/s ²
Factor	2.78 x10 ⁻⁴	8.47x10 ⁻⁵	0.3048	0.0254
↓				
SI system	m/s ²			

Unit	kgf	lb (force)	oz (force)
Factor	9.81	4.45	0.278
↓			
SI system	N		

Unit	lb.	oz.
Factor	0.4535	0.02835
↓		
SI system	kg	

Unit	deg.	min.	sec.
Factor	0.01755	2.93x10 ⁻⁴	4.88x10 ⁻⁶
↓			
SI system	rad		

Unit	deg/s	deg/min	r/s	r/min
Factor	0.01755	2.93x10 ⁻⁴	6.28	0.1047
↓				
SI system	rad/s			

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Appendix

(8) Angular acceleration

SI system	rad/s ²	
↓		
Unit	deg/s ²	deg/min ²
Factor	57.3	3.44x10 ³

Unit	deg/s ²	deg/min ²
Factor	0.01755	2.93x10 ⁻⁴
↓		
SI system	rad/s ²	

(9) Torque

SI system	N·m			
↓				
Unit	kgf·m	lb·ft	lb·in	oz·in
Factor	0.102	0.738	8.85	141.6

Unit	kgf·m	lb·ft	lb·in	oz·in
Factor	9.81	1.356	0.1130	7.06x10 ⁻³
↓				
SI system	N·m			

(10) Inertia moment

SI system	kg·m ²							
↓								
Unit	kgf·m·s ²	kgf·cm·s ²	lb·ft ²	lb·ft·s ²	lb·in ²	lb·in·s ²	oz·in ²	oz·in·s ²
Factor	0.102	10.2	23.73	0.7376	3.42x10 ³	8.85	5.47x10 ⁴	141.6

Unit	kgf·m·s ²	kgf·cm·s ²	lb·ft ²	lb·ft·s ²	lb·in ²	lb·in·s ²	oz·in ²	oz·in·s ²
Factor	9.81	0.0981	0.0421	1.356	2.93x10 ⁻⁴	0.113	1.829x10 ⁻⁵	7.06x10 ⁻³

↓								
SI system	kg·m ²							

(11) Torsional spring constant, moment stiffness

SI system	N·m/rad				
↓					
Unit	kgf·m/rad	kgf·m/arc-min	kgf·m/deg	lb·ft/deg	lb·in/deg
Factor	0.102	2.97 x10 ⁻⁵	1.78x10 ⁻³	0.0129	0.1546

Unit	kgf·m/rad	kgf·m/arc-min	kgf·m/deg	lb·ft/deg	lb·in/deg
Factor	9.81	3.37 x10 ⁴	562	77.6	6.47

↓					
SI system	N·m/rad				

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Appendix

A-2 Calculating inertia moment

Formula of mass and inertia moment

(1) Both centerlines of rotation and gravity are the same:

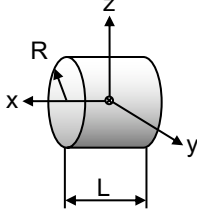
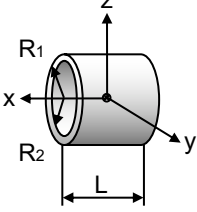
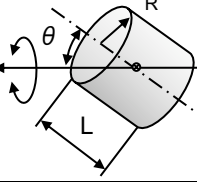
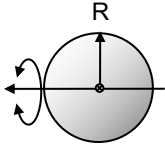
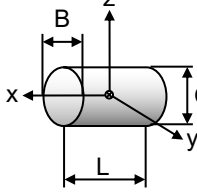
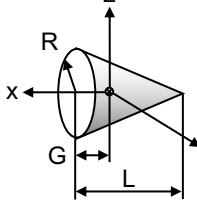
The following table includes formulas to calculate mass and inertia moment.

m : mass [kg], I_x, I_y, I_z : inertia moments which rotates around x-, y-, z-axes respectively [$\text{kg} \cdot \text{m}^2$]

G : distance from end face of gravity center [m]

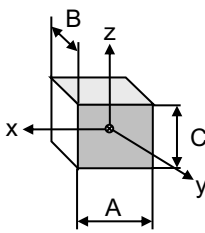
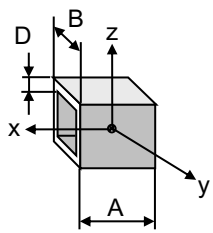
ρ : specific gravity [$\times 10^3 \text{kg} / \text{m}^3$]

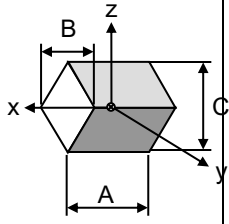
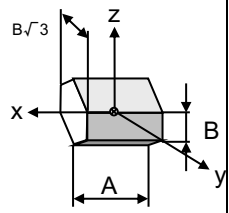
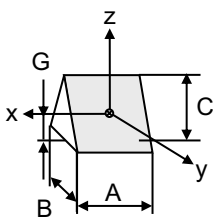
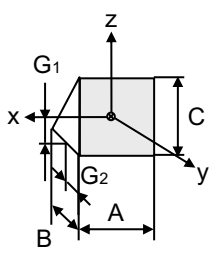
Unit Inertia moment [$\text{kg} \cdot \text{m}^2$]

Object form	Mass, inertia, gravity center	Object form	Mass, inertia, gravity center
	$m = \pi R^2 L \rho$ $I_x = \frac{1}{2} m R^2$ $I_y = \frac{1}{4} m \left(R^2 + \frac{L^2}{3} \right)$ $I_z = \frac{1}{4} m \left(R^2 + \frac{L^2}{3} \right)$	 <p>R1: Outer diameter R2: Inner diameter</p>	$m = \pi (R_1^2 - R_2^2) L \rho$ $I_x = \frac{1}{2} m (R_1^2 + R_2^2)$ $I_y = \frac{1}{4} m \left\{ (R_1^2 + R_2^2) + \frac{L^2}{3} \right\}$ $I_z = \frac{1}{4} m \left\{ (R_1^2 + R_2^2) + \frac{L^2}{3} \right\}$
	$m = \pi R^2 L \rho$ $I_\theta = \frac{1}{12} m \times \left\{ 3R^2(1 + \cos^2\theta) + L^2 \sin^2\theta \right\}$		$m = \frac{4}{3} \pi R^3 \rho$ $I = \frac{2}{5} m R^2$
	$I_x = \frac{1}{16} m (B^2 + C^2)$ $I_y = \frac{1}{4} m \left(\frac{C^2}{4} + \frac{L^2}{3} \right)$ $I_z = \frac{1}{4} m \left(\frac{B^2}{4} + \frac{L^2}{3} \right)$		$m = \frac{1}{3} \pi R^2 L \rho$ $I_x = \frac{3}{10} m R^2$ $I_y = \frac{3}{80} m (4R^2 + L^2)$ $I_z = \frac{3}{80} m (4R^2 + L^2)$ $G = \frac{L}{4}$

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Appendix

Rectangular pillar		Square pipe	
	$m = ABC\rho$ $I_x = \frac{1}{12} m(B^2 + C^2)$ $I_y = \frac{1}{12} m(C^2 + A^2)$ $I_z = \frac{1}{12} m(A^2 + B^2)$		$m = 4AD(B - D)\rho$ $I_x = \frac{1}{3} m\{(B \cdot D)^2 + D^2\}$ $I_y = \frac{1}{6} m\left\{\frac{A^2}{2} + (B \cdot D)^2 + D^2\right\}$ $I_z = \frac{1}{6} m\left\{\frac{A^2}{2} + (B \cdot D)^2 + D^2\right\}$

Object form	Mass, inertia, gravity center	Object form	Mass, inertia, gravity center
Rhombus pillar 	$m = \frac{1}{2} ABC\rho$ $I_x = \frac{1}{24} m(B^2 + C^2)$ $I_y = \frac{1}{24} m(C^2 + 2A^2)$ $I_z = \frac{1}{24} m(B^2 + 2A^2)$	Hexagonal pillar 	$m = \frac{3\sqrt{3}}{2} AB^2\rho$ $I_x = \frac{5}{12} mB^2$ $I_y = \frac{1}{12} m\left(A^2 + \frac{5}{2}B^2\right)$ $I_z = \frac{1}{12} m\left(A^2 + \frac{5}{2}B^2\right)$
Isosceles triangle pillar 	$m = \frac{1}{2} ABC\rho$ $I_x = \frac{1}{12} m\left(\frac{B^2}{2} + \frac{2}{3}C^2\right)$ $I_y = \frac{1}{12} m\left(A^2 + \frac{2}{3}C^2\right)$ $I_z = \frac{1}{12} m\left(A^2 + \frac{B^2}{2}\right)$ $G = \frac{C}{3}$	Right triangle pillar 	$m = \frac{1}{2} ABC\rho$ $I_x = \frac{1}{36} m(B^2 + C^2)$ $I_y = \frac{1}{12} m\left(A^2 + \frac{2}{3}C^2\right)$ $I_z = \frac{1}{12} m\left(A^2 + \frac{2}{3}B^2\right)$ $G_1 = \frac{C}{3} \quad G_2 = \frac{B}{3}$

● Example of specific gravity

The following tables show references of specific gravity. Confirm the specific gravity for the material of the drive load.

Material	Specific gravity [$\times 10^3 \text{kg} / \text{m}^3$]	Material	Specific gravity [$\times 10^3 \text{kg} / \text{m}^3$]	Material	Specific gravity [$\times 10^3 \text{kg} / \text{m}^3$]
SUS304	7.93	Aluminum	2.70	Epoxy resin	1.90
S45C	7.86	Duralumin	2.80	ABS	1.10
SS400	7.85	Silicon	2.30	Silicon resin	1.80
Cast iron	7.19	Quartz glass	2.20	Polyurethane rubber	1.25
Copper	8.92	Teflon	2.20		
Brass	8.50	Fluorocarbon resin	2.20		

(2) Both centerlines of rotation and gravity are not the same:

The following formula calculates the inertia moment when the rotary center is different from the gravity center.

$$I = I_g + mF^2$$

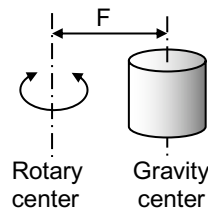
I: Inertia moment when the gravity center axis does not match the rotational axis [$\text{kg} \cdot \text{m}^2$]

I_g : Inertia moment when the gravity center axis matches the rotational axis [$\text{kg} \cdot \text{m}^2$]

Calculate according to the shape by using formula (1).

m: mass [kg]

F: Distance between rotary center and gravity center [m]



(3) Inertia moment of linear operation objects

The inertia moment, converted to actuator axis, of a linear motion object driven by a screw, etc., is calculated using the formula below.

$$I = m\left(\frac{P}{2\pi}\right)^2$$

I: Inertia moment of a linear operation object converted to actuator axis [$\text{kg}\cdot\text{m}^2$]

m: mass [kg]

P: Linear travel per actuator one revolution [m/rev]

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Warranty Period and Terms

The equipment listed in this document is warranted as follows:

■ **Warranty period**

Under the condition that the actuator are handled, used and maintained properly followed each item of the documents and the manuals, all the applicable products are warranted against defects in workmanship and materials for the shorter period of either one year after delivery or 2,000 hours of operation time.

■ **Warranty terms**

All the applicable products are warranted against defects in workmanship and materials for the warranted period. This limited warranty does not apply to any product that has been subject to:

- (1) user's misapplication, improper installation, inadequate maintenance, or misuse.
- (2) disassembling, modification or repair by others than Harmonic Drive Systems, Inc.
- (3) imperfection caused by a non-applicable product.
- (4) disaster or others that does not belong to the responsibility of Harmonic Drive Systems, Inc.

Our liability shall be limited exclusively to repairing or replacing the product only found by Harmonic Drive Systems, Inc. to be defective. Harmonic Drive Systems, Inc. shall not be liable for consequential damages of other equipment caused by the defective products, and shall not be liable for the incidental and consequential expenses and the labor costs for detaching and installing to the driven equipment.

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