Linear Motor

Operation Manual

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MP99UE01-2110

Revision History

Release Date	Version	Applicable Product	Revision Contents
Mar. 2021	V1.0	Linear motor	New Version Release
Oct. 2021	V1.1	Linear motor	1. Modify the flatness tolerance of motor assembly. 2. Add the description of Hall's air gap. 3. Add LMSA-Z series to the description of extension cable installation 4. Add the selection of copper pillar for motor with connecter. 5. Correct the pin of signal.

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1. Installation and Safety Guide

1.1 General precautions

Before using the product, please carefully read through this manual. HIWIN Mikrosystem (HIWIN) is not responsible for any damages, accidents, or injuries caused by failure in following the installation instructions and operating instructions stated in this manual.

- Before installing or using the product, ensure there is no damage to its appearance. If any damage is found after inspection, please contact HIWIN or local distributors.
- Do not disassemble or modify the product. The design of the product has been verified by structural calculation, computer simulation, and actual testing. HIWIN is not responsible for any damage, accident or injury caused by disassembly or modification done by users.
- Keep children away from the product.
- Anyone with a pacemaker or A.I.C.D is prohibited from using the product.
- The product should be operated only by personnel with experience and technical knowledge.

1.2 Description of safety notices and Safety symbols

Safety notices are always indicated using a signal word and sometimes also a symbol for the specific risk.
The following signal word and risk levels are used:

⚠ DANGER!
Imminent danger!
Non-compliance with the safety notices will result in serious injury or death!

⚠ WARNING!
Potentially dangerous situation!
Non-compliance with the safety notices runs the risk of serious injury or death!

ATTENTION!
Potentially dangerous situation!
Non-compliance with the safety notices runs the risk of damage to property or environmental pollution!

The following symbols are used in this user manual:

Warning and prohibition signs			
	No access for people with active implanted cardiac devices.		Substance hazardous to the environment!
	Warning!		Warning of crushing of hands!
	Warning of electricity!		Warning of hot surface!
	Warning of magnetic field!		

1.3 Safety instructions

⚠ DANGER!

Risk of death as a result of permanent magnet fields

Even when the motor is switched off, the permanent magnets can put people with active medical implants at risk if they are close to the motor.

Stator assembly has a strong magnetic field; users must handle with care. Otherwise, personnel may get injured and the stator may be damaged.

- During assembly of stator to system structure, keep any magnetic material at a distance to prevent the risk of injury to hands.
- Do not touch the forcer and stator during operation.
- If you are affected, stay at a minimum distance of 500 mm from the motors (trigger threshold for static magnetic fields of 0.5 mT as per directive 2013/35/EU).

⚠ WARNING!

Risk of Linear motor assembly.

Danger of crushing by permanent magnets of the stator

The attraction forces of the stator act on materials that can be magnetized. The forces of attraction increase significantly close to the stator.

There is a significant risk of crushing when you are close to the stators.

Close to the stators, the forces of attraction can be several kN - example:

Magnetic attractive forces are equivalent to a force of 100 kg, which is sufficient to trap a body part.

- The product should be installed and operated by specialized personnel.
- During assembly, avoid using magnetic tools and screws.
- Before fixing the stator, please adhere the label of strong magnetic field to the position where it can easily be seen to prevent personnel from injury.
- Whenever disassembling the stator, do not handle the stator with the edge of the cover directly. Otherwise, personnel may get injured and the stator may be damaged.
- Never unpack several secondary sections at the same time.
- Never place secondary sections next to one another without taking the appropriate precautions.

⚠ WARNING!

Risk of Linear motor operate.

When incorrectly operated and in the case of a fault, the motor can overheat resulting in fire and smoke. This can result in severe injury or death. Further, excessively high temperatures destroy motor components and result in increased failures as well as shorter service lives of motors.

- Operate the motor according to the relevant specifications.
- Allow the forcer to cool down sufficiently (in a 25°C room temperature) before working around the product to avoid burns.
- When an abnormal smell, noise, smoke, or vibration is detected, please turn off the power immediately.

⚠ WARNING!

Burn injuries caused by hot surfaces

In operation, the motor can reach high temperatures, which can cause burns if touched.

- Operate the motor according to the relevant specifications.
- Allow the motor to cool down before starting any work.
- Use the appropriate personnel protection equipment, e.g. gloves.

ATTENTION!

Damage caused by assembly.

Electric fields or electrostatic discharge can cause malfunctions through damaged Individual components, integrated circuits, modules or devices.

- Keep magnetic storage media or precision instruments away from the product to avoid damage-caused fields. (e.g., magnetic scale, watch, credit card and magnetic response device).
- Precautions should be taken for ESD (Electrostatic Discharge), like wearing gloves, shoes, etc.
- Do not drag the cables while moving or placing the forcer and stator units.
- Do not damage or bend the cables to avoid electric shock.
- Be sure to confirm that there is no interference with other components in the operations. Confirm that the cable bending radius is large enough to prevent reducing the lifetime of the cables.

ATTENTION!

Product precautions.

Product appearance description and avoid damage caused by improper disassembly.

- Clean stator surface by using disposable cotton rags and cleaning liquid such as isopropanol alcohol (95% Vol.). It is suggested to clean the surface once every three months or once every two weeks in high fume formation rate facilities with machines such as PCB machines or drilling machines.
- The products with epoxy have some spots on the surface, and it is a natural phenomenon.
- The product can only be repaired by HIWIN engineers. Please send the product back to HIWIN if there are any unusual occurrences.
- Do not change or disassemble the components by yourself. HIWIN will not take responsibility for any accidents or damages to the forcer and stator caused by this.
- A one year guarantee is provided from the date of delivery. HIWIN will not be held responsible for replacing or maintaining a product which has been incorrectly handled (please refer to the notes and instructions in this manual) or damaged due to natural disasters.

- When taking or placing the product, do not just pull the cable and drag it.
- Do not subject the product to shock.
- Ensure the product is used with rated load.
- According to IEC 60034-5 standard, HIWIN Linear motor have the class of protection (refer to 1.3.4).
- HIWIN Linear motor have a thermal class F according to IEC 60085 standard.

- HIWIN Linear motor certification test meets the following standards.

CE	LVD Safety: 2014/35/EU reference standard	EN60034-1:2010
	EMC: 2014/30/EU reference standard	EN61000-6-4:2007/A1:2011
		EN61000-6-2:2005
UL	Linear motor reference standard 1004-1	

1.3.1 Intended use

- Only use the motors for industrial systems.
- The motor must avoid dirt and contact with corrosive substance.
- Do not install the motors in hazardous zones, if the motors have not label and description.
- Ensure that the installation conditions conform the specifications.
- The Linear motor systems must not be operated:
  - Outdoors.
  - In potentially explosive atmospheres.

1.3.2 Wiring precautions

- Before using the product, carefully read through the specification noted on the product label, and ensure the product is used with power supply specified in the product requirement.
- Check if the wiring is correct. Incorrect wiring may make the motor operate abnormally, or even cause permanent damage to the motor.
- Select extension cord with shielding. The shielding must be grounded.
- Do not connect power cable and temperature sensor cable to the same extension cord.
- Power cable and temperature sensor cable contain shielding. The shielding must be grounded.

1.3.3 Maintenance and storage precautions

⚠ WARNING!

Product precautions.
If you do not correctly dispose of direct drives or their components (especially components with permanent magnets), then this can result in death, severe injury and/or material damage.

- Disposal method of the damaged product: recycle it according to local laws and regulations.
- Refer to Chapter 8 for related disposal methods.

- Store the Linear motor components in their transport packaging.
- Do not store the Linear motor components in explosive atmospheres or in environments exposed to chemicals.
- Only store the Linear motor components in dry, frost-free areas with a corrosion-free atmosphere.
- Make sure that the motors are not subjected to vibrations or impacts while in storage.
- Clean and protect used Linear motor components before storage.
- When storing the components, attach signs warning of magnetic fields.

Operating environment	Temperature	0~40°C
	Humidity	5~85%
Storage environment	Temperature	-5℃~40°C
	Humidity	5~85%
Altitude		Below 1000M
Temperature variation speed		Maximum 0.5K/min
Condensation		Not allowed
Frozen		Not allowed

1.3.4 Transport precautions

- Permanent magnets are listed as Dangerous Goods (Magnetized material: UN2807) according to International Air Transport Association (IATA).
- For products containing permanent magnets, no additional measures on packaging are required to resist the magnetic field in sea freight and inland transportation.
- When transporting products containing permanent magnets by air, the maximum permissible magnetic field strengths specified by the appropriate IATA Packing Instruction must not be exceeded. Special measures may be required so that these products can be shipped. Above a certain magnetic field strength, such shipments must be labelled in accordance with Packing Instruction 953 from IATA (Please refer below or the latest regulation from IATA.)

- Products whose highest field strength exceeds 0.418 $A\ m/$(0.525 μT) or 2° of compass deviation, as determined at a distance of 4.6 m from the product, require shipping authorization from the responsible national body of the country from where the product is being shipped (country of origin) and the country where the airfreight company is based. Special measures need to be taken to enable the product to be shipped.
- When shipping products whose highest field strength is equal to or greater than 0.418 $A\ m/$(0.525 μT) or 2° of compass deviation, as determined at a distance of 2.1 m from the product, shipment is conducted with regulation of Dangerous Goods Transportation.
- When shipping products whose highest field strength is less than 0.418 $A\ m/$(0.525 μT), as determined at a distance of 2.1 m from the product, you do not have to notify the relevant authorities and you do not have to label the product.

- Shipping originally packed motor components neither has to be disclosed nor marked.
- Transport conditions must comply with EN 60721-3-2 (Please refer Table 1.3-1 on the next page).

Table 1.3-1 Transport conditions

Environmental parameter	Unit	Value
Air temperature	(℃)	-5~40
Relative humidity	(%)	5~85
Rate of change of temperature	(℃/min)	0.5
Condensation		Not allowed
Formation of ice		Not allowed
Transport condition		Class 2K2
Transport the motor in an environment with good weather protection (indoor/factory)		
Biological conditions	Class 2B1	
Chemically active substances	Class 2C1	
Mechanically active substances	Class 2S2	
Mechanical conditions	Class 2M2	

1.4 Power supply and controller selection

The continuous current, peak current and bus voltage must be considered while selecting a power supply. In addition, the resonance effect which can be induced in motors by some drive systems must be taken into account. Motors are assembled with several individual coils connected in series. Each one of these coils has an inductance in series and a stray capacitance to earth. The LC network obtained possesses a resonant frequency, so when an electrical oscillation is applied to the phase inputs (in particular the PWM frequency), the neutral point of the motor can oscillate with very high amplitudes with respect to earth, and the insulation can be damaged as a consequence of these oscillations. This phenomenon is more pronounced in motors with a large number of poles (such as Linear motors).

Under ideal conditions, the 600 V_{DC} bus voltage generated by the power supply should be ±300 V_{DC} relative to earth. However, in some configurations, the voltage between the buses and earth will have an oscillating voltage, and the peak of the high voltage will be transmitted to the motor. The oscillation between voltage and earth depends on system characteristics. By experience, a system with few axes connected to the bus voltage is less liable to have disturbing oscillations on the bus, but for example in a large machine tool with many axes and several spindles, the oscillations can reach high amplitudes. If the frequency of these oscillations is close to the resonant frequency of the motor, it can lead to over-voltage failures on the neutral point.

The case where the PWM frequency of the controller happens to correspond to the resonant frequency of the motor. In this case, the fundamental harmonic of the PWM frequency is directly exciting the resonant frequency of the motor, and very high voltages are thus obtained on the neutral point. Also, as the PWM voltage is a square wave, it contains odd harmonics (1, 3, 5, 7, etc..) that can also excite the motor resonance. Fortunately, these harmonics have a smaller amplitude that the fundamental.

In another case, it may also lead an over-voltage failure. In this case, the fundamental harmonic of the PWM frequency is directly exciting the resonant frequency of the motor, and very high voltages are thus obtained on the neutral point. In addition, because the PWM voltage is a square wave, it contains odd harmonics (1, 3, 5, 7, etc.) that can also excite motor resonance.
In conclusion, to prevent any failure from occurring, two elements must be considered: the oscillations between the bus voltage and earth and the PWM frequency. If both elements above do not enter into resonance with the motor, then there is no risk for the motor.
When selecting power supply, please check the conditions below:

- 300 V_{DC} controller: 750 V_p (phase to ground), voltage gradient: 8 kV/μs.
- 600 or 750 V_{DC} controller: 1000 V_p maximum (at the PWM frequency) and spikes up to 1400 V (earth to peak and for a few μs) and a voltage gradient: 11 kV/μs.

The cable between the controller and the motor will generate a reflected wave due to the impedance mismatch between the cable and the motor, and the reflected voltage will be superimposed with the subsequent input voltage, causing the voltage to rise. This phenomenon will be more obvious when the motor cable is longer. If the length of the cable between the controller and the motor is longer than 10 m, it is necessary to measure voltages at the motor terminals to ensure they are lower than specified above. If the measured value is greater, a dV/dt filter must be inserted between the controller and the motor for protection.

1.5 Motor IP protection class

Linear motor applies to IEC to define the protection class. The first number of IP□□ means the protection class against dust ingress. Class 6 refers to total protection against dust ingress. The second means protection class against water ingress. Class 0 means no protection. Class 5 means protection against low pressure water jets from any direction. Class 6 means protection against high pressure water jets from any direction.

- IP protection class for different motor types.

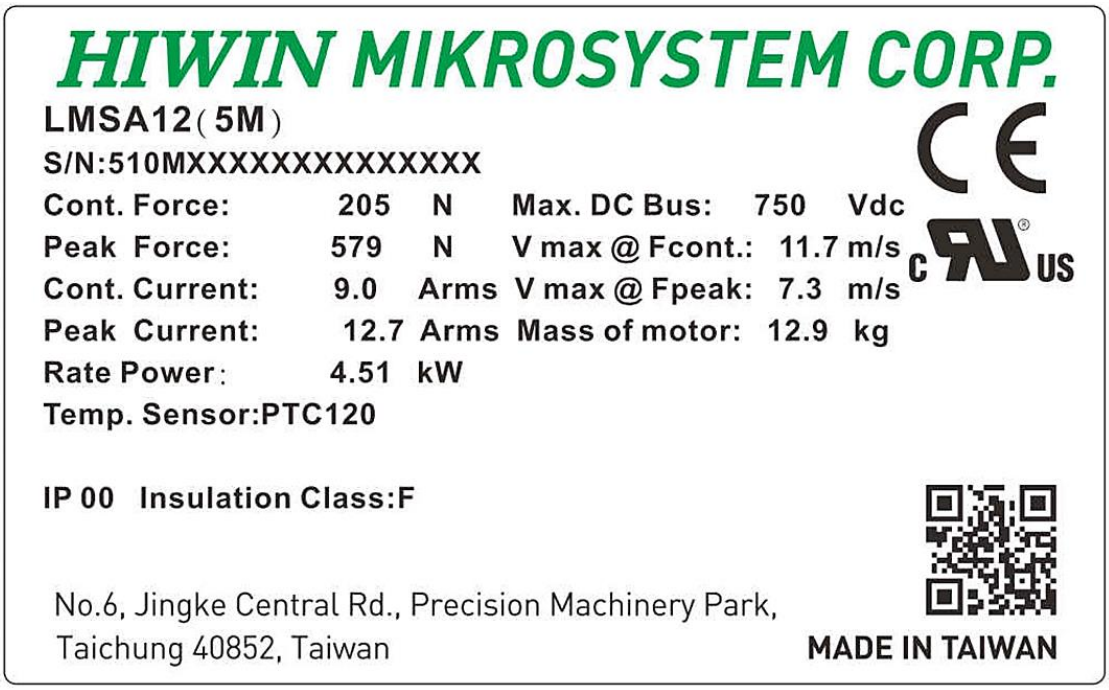
Linear motor	Protection class
LMSA	IP60
LMFA	IP60
LMFP	IP65
LMSC	IP60
LMC	IP60
LMSS	IP60
LMT	IP66

The stators are largely protected against corrosion by their mechanical design. however, suitable constructive measures have to be taken to prevent that ferromagnetic particles (for example, iron chips) accumulate on the stator.

Contact with liquids and general contact with corrosive media must be avoided by suitable protective measures (encapsulation, bellows, protective lacquer).

1.6 Type plate

- Information about the type plates for the different motor types. (Type plate example)



2. Linear Motor Introduction

2.1 Linear motor introduction

Linear motors can be divided into iron core and ironless linear motors. An iron core linear motor has a relatively greater thrust force, and an ironless linear motor is relatively more compact with greater dynamic characteristics. Since there is no transmission mechanism between the motor and the load, the load can be driven directly. Accordingly, the mechanism is relatively simple and a remarkable dynamic response can be achieved. Furthermore, linear motors adopt the contactless design such that there is no wear and higher precision can be provided while the maintenance and care required can also be reduced. The stator of a linear motor adopts the module assembly method and the number of acceptable assemblies is unlimited such that the length of the stroke is not restricted.

2.2 Linear motor structure

2.2.1 Iron core linear motor (LMSA/LMSA-Z/LMSS) structure

LMSA/LMSA-Z/LMSS product is an iron core motor, and the forcer consists of an iron core, coil and epoxy assembled together. Since the iron core interacts with the magnet, this series of motor is affected by the cogging force and the attraction force between the forcer and stator. Accordingly, during the design of the forcer installation base, it is necessary to consider such factors. This product is suitable to be used for high acceleration and deceleration applications, such as: conveyor/transportation equipment, digital printing, 3D printing, PCB drilling machine, Light processing machine etc.

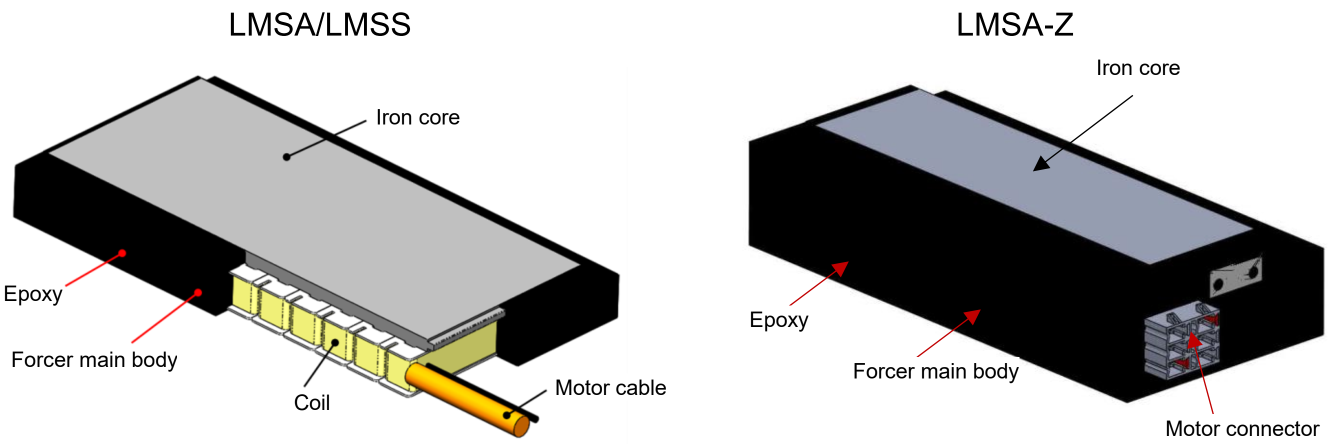


Figure 2.2-1 Forcer structure

The stator of LMSA//LMSA-Z/LMSS, as viewed from the top, is of a rectangular structure. Customers can select the Cover or Epoxy version of the stator according to the industrial application. In addition, the stator can also be used as a moving part.

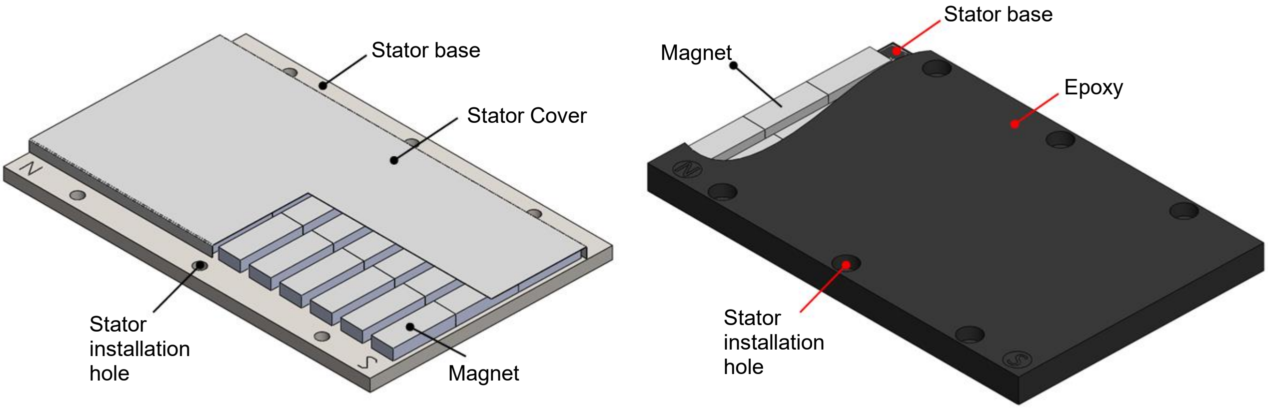
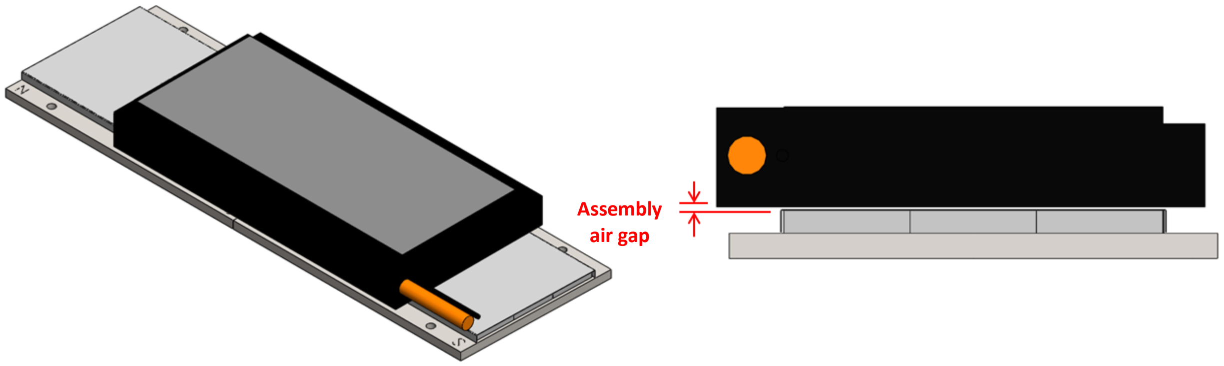


Figure 2.2-2 Stator structure

During the installation of the motor, please be aware of the air gap between the forcer and the stator. For the relationship between the air gap of an iron core linear motor and the motor performance, please refer to Chapter 3.2 of the Manual.
For the installation guidelines on the forcer and stator of the motor, please refer to Chapter 5.1 of the Manual. Since a strong attraction force exists between the forcer and stator, please do not arbitrarily remove the stator and do not use magnetic material to approach the device in order to prevent any danger. In addition, the stator assembly length must be greater than the length of the forcer; otherwise, unexpected risk may occur.

LMSA/LMSS



LMSA-Z

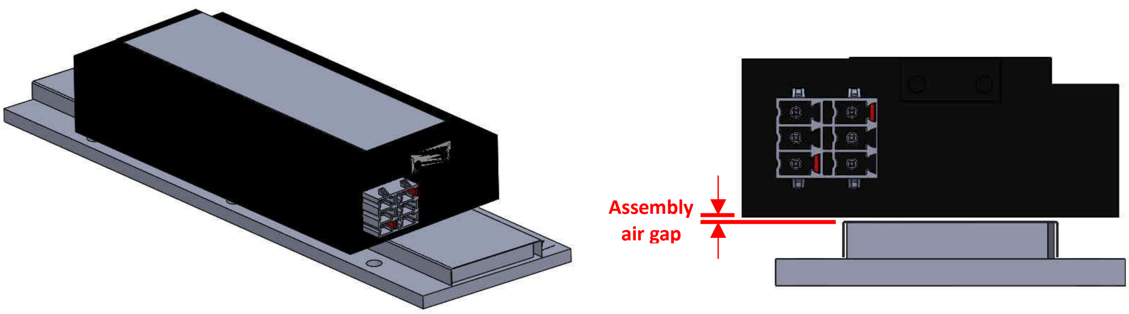


Figure 2.2-3 Forcer and stator structure

2.2.2 Water-cooling linear motor (LMFA/LMFP) structure

LMFA/LMFP product is an iron core water-cooling motor, and the forcer consists of an iron core, forcer base, coil, cooling copper tube and epoxy assembled together. Since the iron core interacts with the magnet, this series of motor is affected by the cogging force and the attraction force between the forcer and stator. Accordingly, during the design of the forcer installation base, it is necessary to consider such factors. This product utilizes a cooling system to increase the motor performance, and it is suitable to be used for heavy load applications, such as: conveyor/transportation equipment, PCB drilling machine, grinding machine etc.

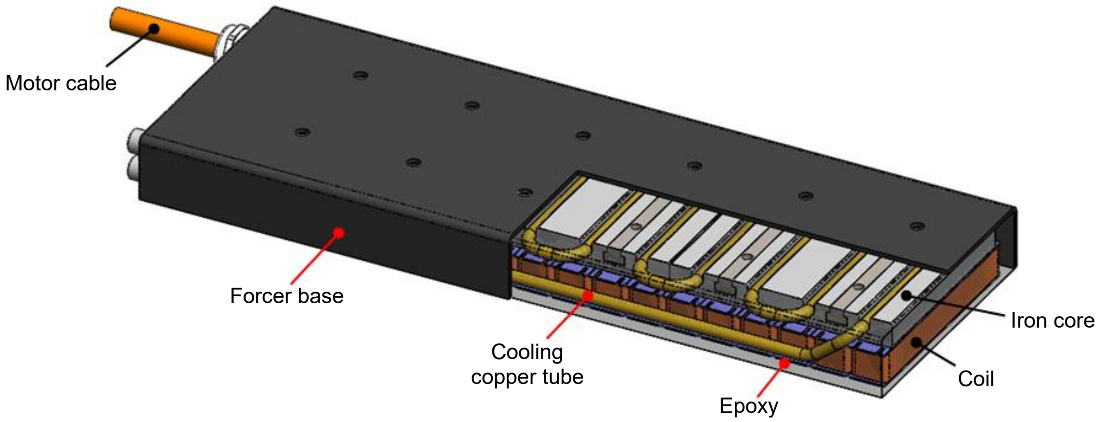


Figure 2.2-4 Forcer structure

The stator of LMFA/LMFP, as viewed from the top, is of a rectangular structure. Customers can select the Cover or Epoxy version of the stator according to the industrial application.

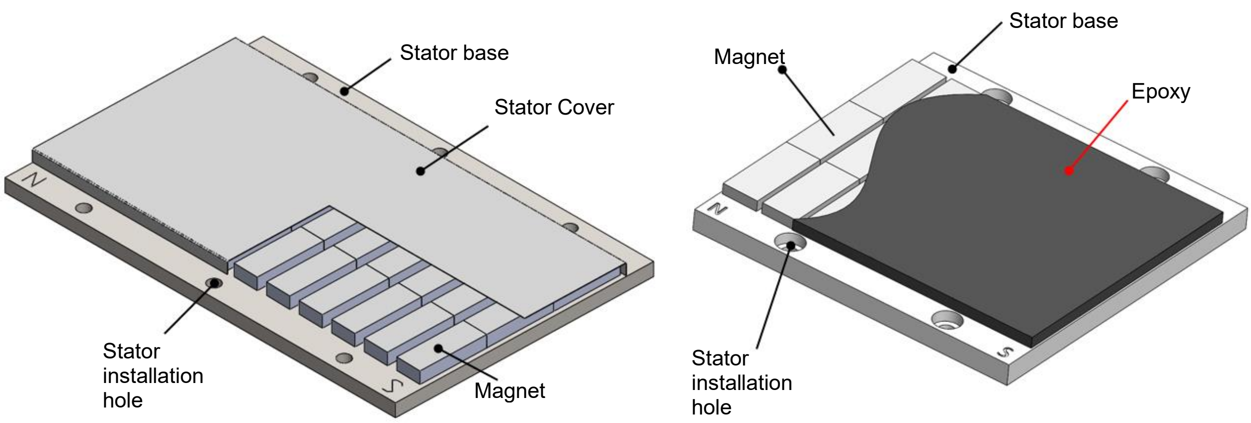


Figure 2.2-5 Stator structure

During the installation of the motor, please be aware of the air gap between the forcer and the stator. For the relationship between the air gap of an iron core linear motor and the motor performance, please refer to Chapter 3.2 of the Manual.
For the installation guidelines on the forcer and stator of the motor, please refer to Chapter 5.1 of the Manual. Since a strong magnetic attraction force exists between the forcer and stator, please do not arbitrarily remove the stator and do not use magnetic material to approach the device in order to prevent any danger. In addition, the stator assembly length must be greater than the length of the forcer; otherwise, unexpected risk may occur.

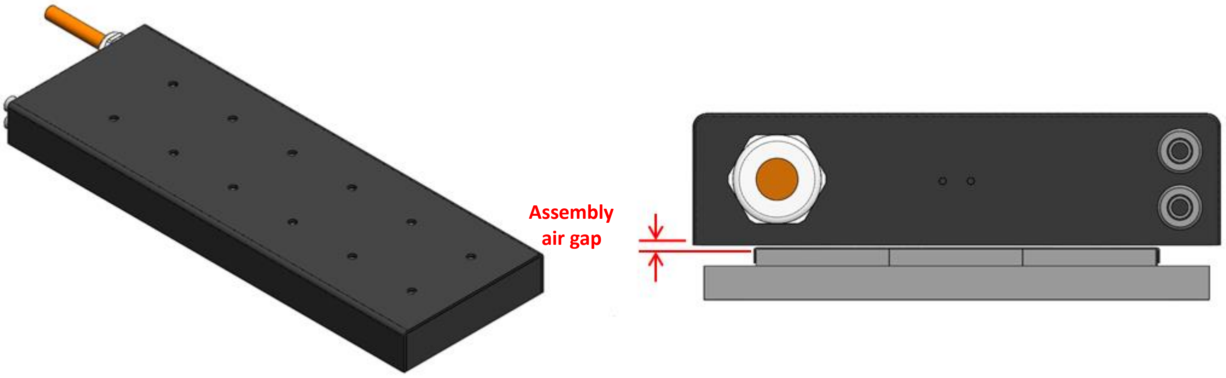


Figure 2.2-6 Forcer and stator structure

2.2.3 Iron linear motor (LMSC) structure

LMSC product is an iron core motor, assembled by iron core, forcer base, coil and epoxy. Since the iron cores are arranged back-to-back, the attraction force between forcer and stator could be offset, load on guideway is greatly reduced and the lifetime of the guideway could be extended. This product is suitable to be used for high acceleration applications such as conveyor / transportation equipment, automation production line and lightweight processing equipment.

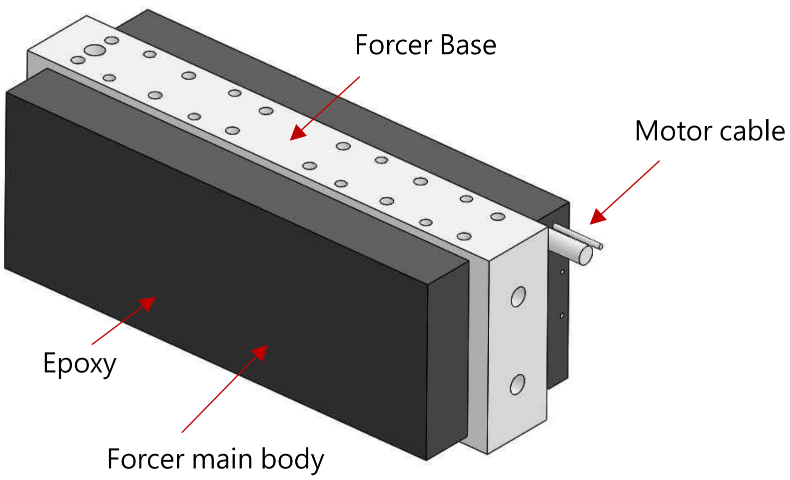


Figure 2.2-7 Forcer structure

2.2.4 Ironless linear motor (LMC) structure

LMC product is an ironless motor. From the force assembly drawing of Figure 2.2-8, it can be understood that the internal of the forcer does not consist of an iron core but coil only, such that it is formed by a forcer base and epoxy assembled together. Since it is an ironless structure, this series of motor has no cogging force, no attraction force between the forcer and stator, and has the characteristic of low inertia. It is suitable to be used for applications of high speed and light load and applications requiring extremely low-speed ripple and low magnetic field dissipation, such as: optical inspection equipment, scanning type electronic microscope equipment etc.

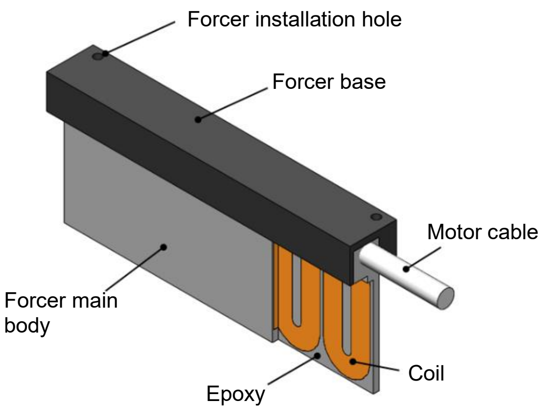


Figure 2.2-8 Forcer structure

The stator of LMC, as viewed from the side, is a U-shape structure, and it consists of a base and two rows of magnets assembled together as shown in Figure 2.2-9. Since the quantity of the magnets is greater than the iron core linear motor, its overall weight is heavier than the forcer. Accordingly, customers are not required to use the stator as a moving part.

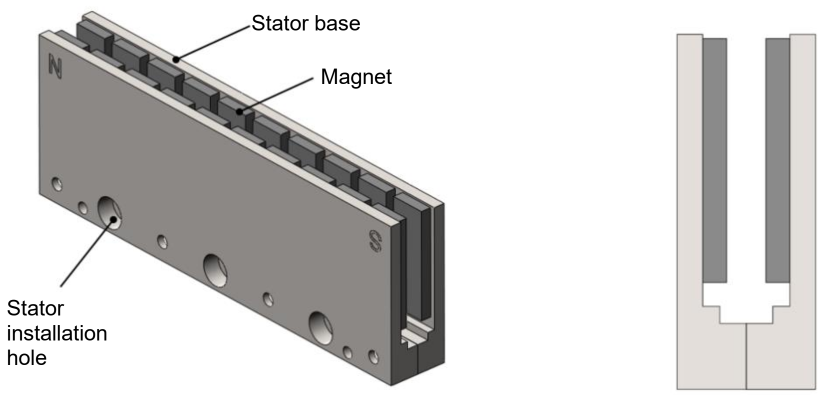


Figure 2.2-9 Stator structure

The cut-out portion of the U-shape structure of the LMC stator is to allow the forcer to move between the stator. During the installation of the motor, please be aware of the assembly gap between the stator, as shown in Figure 2.2-10. For the installation guidelines for the motor forcer and stator, please refer to Chapter 5.2 of the Manual. Since the magnets used by the stator are of strong magnetic attraction force, please do not arbitrarily remove the stator or use magnetic material to approach the stator in order to prevent any danger.

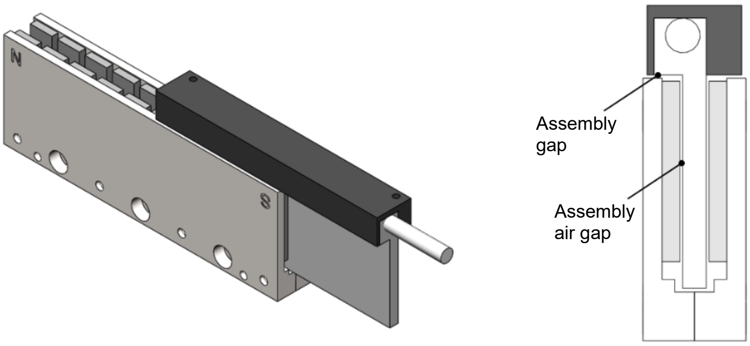


Figure 2.2-10 Forcer and stator structure

2.2.5 Shaft linear motor (LMT) structure

The LMT series product of the Company is an ironless shaft motor. Due to the ironless structure, the motor characteristics are consistent with the characteristics of the LMC series, such that it not has cogging force, the Attraction force, and has the characteristic of low inertia. The forcer assembly is as shown in Figure 2.2-11, and its internal structure is ironless. The difference between LMT and LMC relies on that LMT is a relatively more compact simple structure with an outer appearance resembling a screw shaft linear mechanism, making it easy for maintenance and the mechanism space utilization rate can be increased. For customers changing from screw shaft linear mechanism to direct drive linear mechanism, it is the most optimal solution for use. Its common application includes: optical inspection equipment, machine tool wire cutting equipment, scanning electronic microscope equipment, food automation equipment and medical automation industry etc.

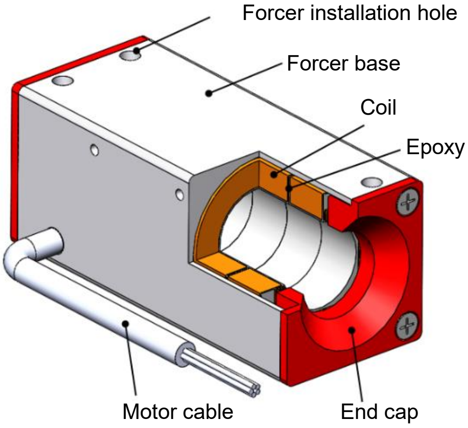


Figure 2.2-11 Forcer structure

The outer appearance of LMT stator is a sealed circular rod, and it is formed by the stator outer tube and magnets, as shown in Figure 2.2-12. During the motor installation, please be aware of the assembly gap between the forcer and stator, as shown in Figure 2.2-12. For the installation guidelines for the motor forcer and stator, please refer to Chapter 5.2 of the Manual. Since the magnets used by the stator are of strong magnetic attraction force, please do not arbitrarily remove the stator or use magnetic material to approach the stator in order to prevent any danger.

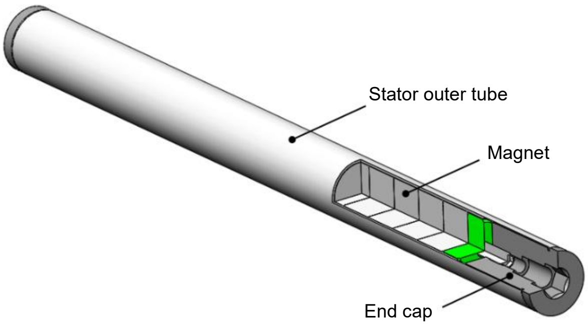


Figure 2.2-12 Stator structure

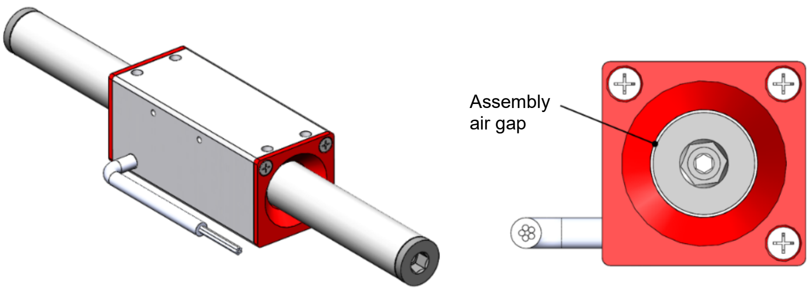


Figure 2.2-13 Forcer and stator structure

2.3 Water-cooling linear motor cooling system

HIWIN LMFA/LMFP series motor adopts the internal water-cooling method to achieve the most optimal motor performance. In addition to the internal water-cooling, LMFA/LMFP series motor is also equipped with the option of LMFC precision water-cooling accessory capable of increasing the heat exchange area and isolating the heat transfer from the motor, in order to significantly reduce the temperature of the machinery of customers. The temperature distribution comparison is as shown in Figure 2.3-1, thereby satisfying the application demand of high precision. Its structure is as shown in Figure 2.3-2.

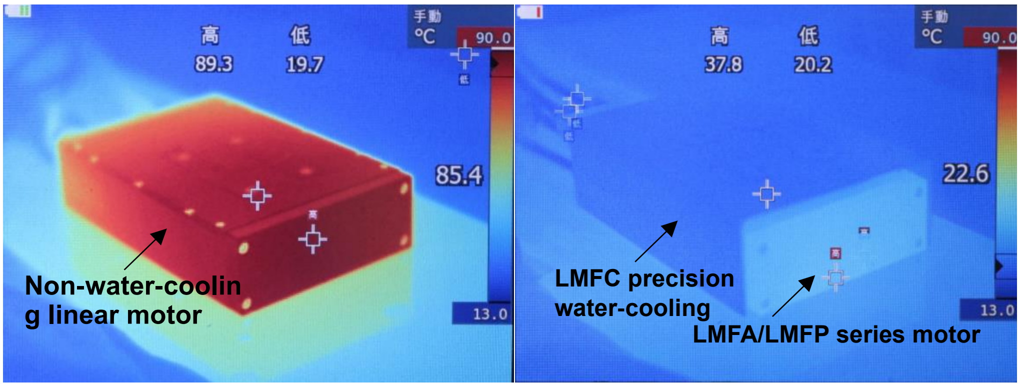


Figure 2.3-1　Temperature distribution comparison image

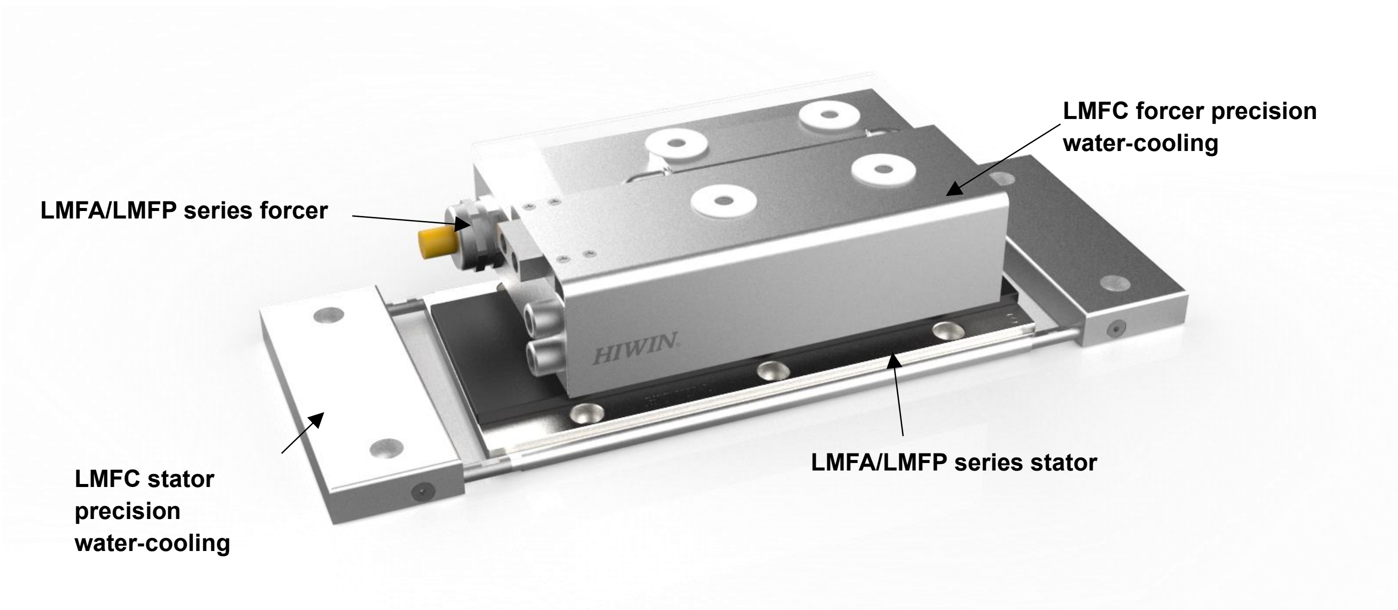


Figure 2.3-2　LMFA/LMFP series with LMFC precision water-cooling motor basic structure

2.3.1 LMFC forcer precision water-cooling

The internal LMFA/LMFP series motor is equipped with coolant channels, and the coolant enters into the internal of the motor from the water-cooling connector inlet to perform cooling. After passing through the sealed channels for heat dissipation, the coolant returns back to the water-cooling machine via the water-cooling connector outlet. For a motor equipped with the LMFC forcer precision water-cooling, a LMFC precision water-
cooling accessory is installed on top of the original LMFA/LMFP forcer. The insulation material provided for the precision water-cooling is used to isolate the heat transfer. The coolant enters into the motor to perform cooling via the water-cooling connector inlet, and after passing through the sealed channels for heat dissipation, it then returns back to the water-cooling machine via the water-cooling connector outlet.

2.3.2 LMFC stator precision water-cooling

The cooling design for the heat dissipation of the stator is only provided for the LMFC precision water-cooling series. The LMFC stator precision water-cooling is installed underneath the LMFA/LMFP stator. The coolant enters into the motor to perform cooling via the water-cooling connector inlet, and after passing through the sealed channels for heat dissipation, it then returns back to the water-cooling machine via the water-cooling connector outlet in order to achieve fast heat dissipation effect.

2.4 Temperature sensor

Linear motors are built-in with a temperature sensor to provide signal to the control system in order to achieve necessary motor over-temperature protection.

Motor protection by temperature monitoring alone using PTC elements can be insufficient. This is the case, for example, if the motor is operated with currents above continuous current.
HIWIN advises the use of additional protective algorithm on the control side. The calculation of max. operating time with currents above continuous current can refer to 3.4.3 .

The common temperature sensors include PTC, Pt1000 etc. For the type of temperature sensors equipped in a motor, please refer to the catalog or acceptance drawings, and the performance of temperature sensors is described in the following respectively:

2.4.1 PTC temperature sensor

PTC 100 and PTC 120 are a thermistor respectively, and their output resistance changes along with the temperature of the coil. The resistance of PTC 100 increases significantly when T_{REF} =100℃, and the resistance of PTC 120 increases significantly when T_{REF} =120℃. Their characteristics are as follows:

Table 2.4-1 PTC temperature sensor characteristics

Temperature	Resistor
$20℃ < \mathrm{T} < \mathrm{T_{REF}} - 20K$	20Ω~250Ω
$T = \mathrm{T_{REF}} - 20K$	≦ 550Ω
$T = \mathrm{T_{REF}} + 5K$	≧ 1330Ω
$\mathrm{T} = \mathrm{T_{REF}} + 15K$	≧ 4000Ω

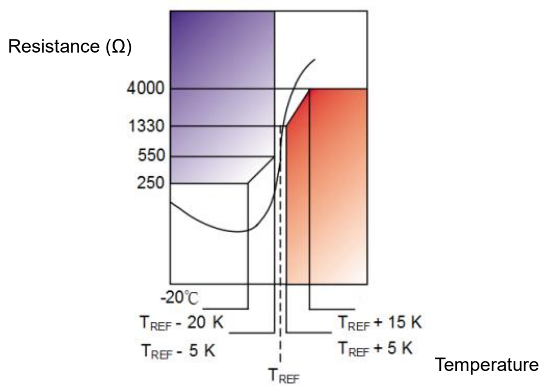


Figure 2.4-1 PTC temperature to resistance relationship graph

2.4.2 Pt1000 temperature sensor

Pt1000 is a platinum resistor temperature sensor (RTD), and its characteristic is that when the temperature is 0°C, its resistance is 1000Ω. The actual temperature can be obtained by measuring the output resistance. The resistance and temperature relationship is as shown in Figure 2.4-2, and the standard equation between the resistance and temperature is expressed in the following:

When the temperature range is -200°C ~ 0°C

$$R_\theta = R_0[1 + A\theta + B\theta^2 + C(\theta - 100)\theta^3]$$

When the temperature range is 0°C ~ 850°C

$$R_\theta = R_0(1 + A\theta + B\theta^2)$$

$R_0 = 1000$ [Ω]
θ =Operating temperature [℃]
$A = 3.9083 \times 10^{-3}$ [°C^{-1}]
$B = -5.7750 \times 10^{-7}$ [°C^{-2}]
$C = -4.1830 \times 10^{-12}$ [°C^{-4}]

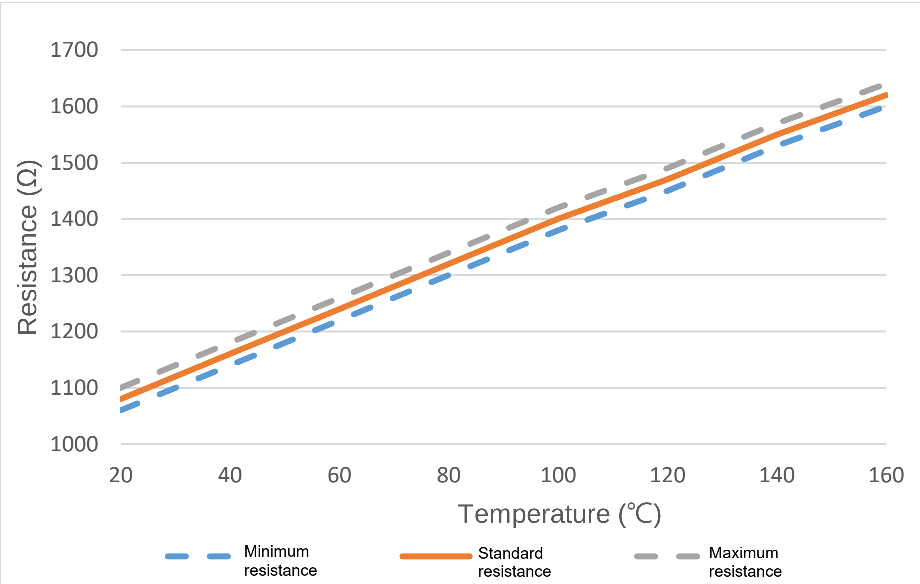


Figure 2.4-2 Pt1000 resistance and temperature relationship graph

2.4.3 KTY84 temperature sensor

KTY84-130 is a silicon temperature sensor, and the actual temperature can be obtained by measuring the output resistance. Its characteristic is as shown in Figure 2.4-3 and the relationship between the resistance and temperature is as shown in Figure 2.4-3

Table 2.4-2 KTY84-130 temperature sensor characteristics

Symbol	Parameter	Criteria	Minimum value	Standard value	Maximum value	Unit
R_{100}	Resistance when temperature below 100℃	$I_{(\mathrm{out})} = 2mA$	970	-	1030	Ω
R_{250} / R_{100}	Resistance ratio	T = 250℃ and 100℃	2.111	2.166	2.221	Ω
R_{25} / R_{100}	Resistance ratio	T = 25℃ and 100℃	0.595	0.603	0.611	Ω

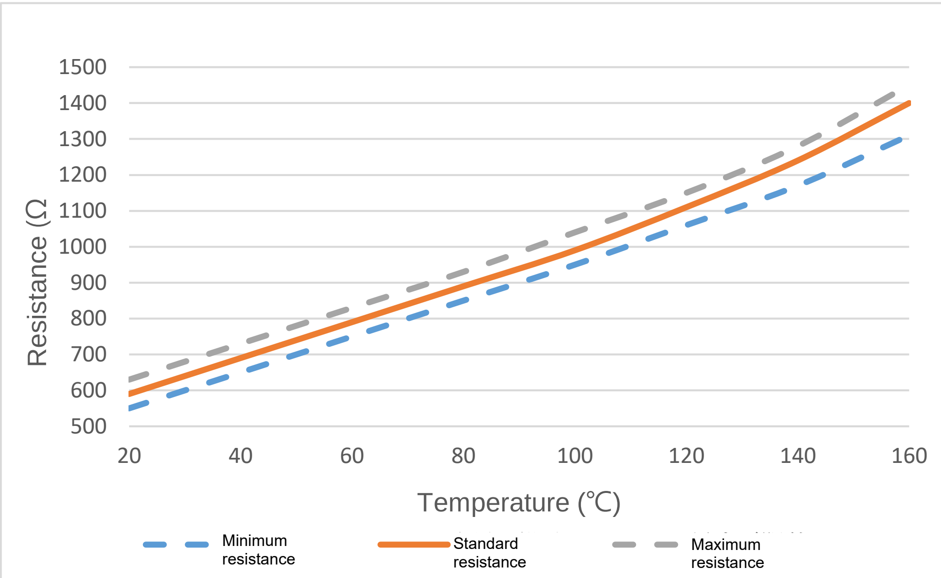


Figure 2.4-3 KTY84-130 resistance and temperature relationship graph

2.4.4 Connection to the drive amplifier

The temperature monitoring circuits can normally be connected directly to the drive control. If the protective separation requirements in accordance with EN61800-5-1 are to be fulfilled, the sensors must be connected to the decoupling modules provided by the drive manufactures.

3. Motor Performance and Water-cooling Motor Cooling System Design

3.1 Linear motor selection

According to the industrial applications, they can be mainly divided into the point-to-point movement and scanning application. Iron core linear motors are suitable for the application of point-to-point movement, and ironless linear motors are suitable for the scanning application, as shown in Figure 3.1-1

Figure 3.1-1　Linear motor application illustration images

3.2 Iron core linear motor Continuous force/peak force, attraction force vs. air gap

The linear motor Continuous force/peak force and the attraction force between the forcer and stator change along with the assembly air gap between the forcer and stator. In this chapter, the relationship between the Continuous force/peak force, attraction force and assembly air gap of each series motor is described in order to provide such information as reference for motor selection and mechanical design.

3.2.1 LMSA Series

■ Continuous force/peak force and air gap

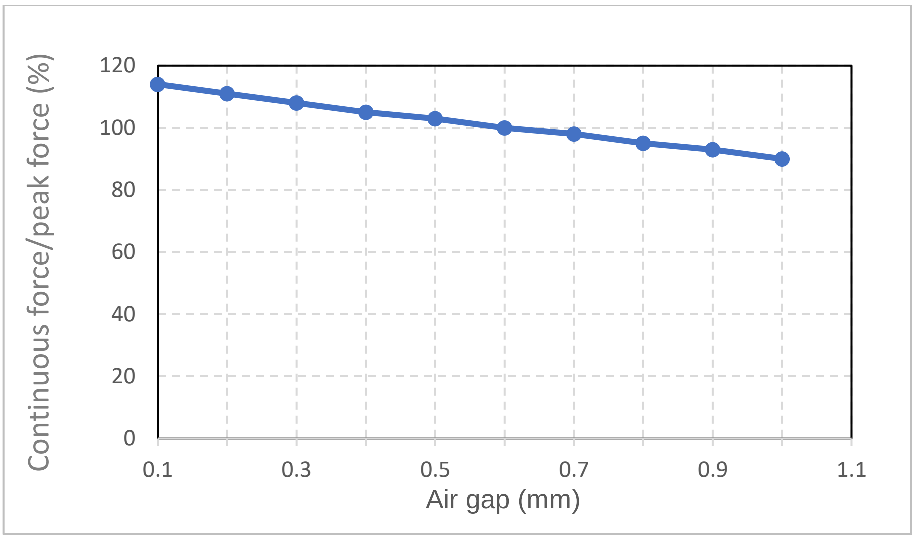


Figure 3.2-1 LMSA Continuous force/peak force-air gap relationship graph

Table 3.2-1 LMSA Continuous force/peak force-air gap comparison chart

Series	LMSA1 □~LMSAC □ / LMSA□□-Z									
Air gap (mm)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Force (%)	114	111	108	105	103	100	98	95	93	90

■ Attraction force and air gap

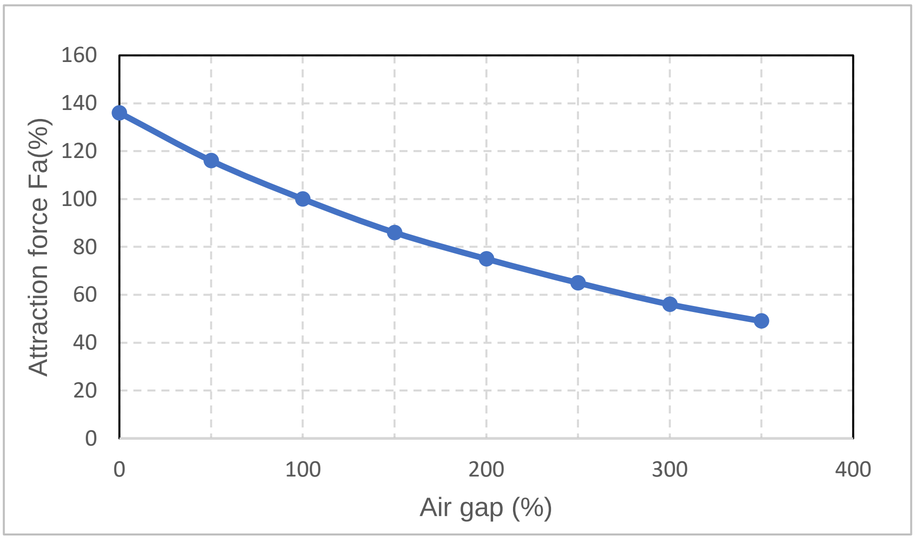


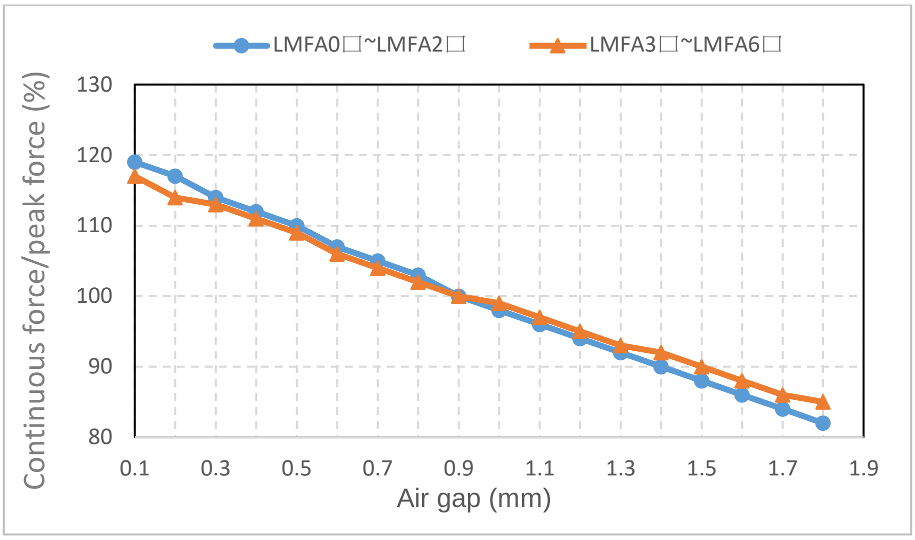
Figure 3.2-2 LMSA attraction force-air gap relationship graph

Table 3.2-2 LMSA attraction force-air gap comparison chart

LMSA1□(-Z) ~LMSA2□(-Z) series attraction force. Unit: N							
Air gap (mm)	LMSA11 LMSA11-Z	LMSA12 LMSA12-Z	LMSA13 LMSA13-Z	LMSA21 LMSA21-Z	LMSA22 LMSA22-Z	LMSA23 LMSA23-Z	LMSA24 LMSA24-Z
0	653	1306	1959	1306	2612	3918	5224
0.3	560	1120	1680	1120	2240	3360	4480
0.6	481	963	1444	963	1926	2888	3851
0.9	415	830	1245	830	1660	2490	3320
1.2	359	718	1077	718	1436	2154	2872
1.5	312	624	936	624	1248	1872	2496
1.8	271	542	813	542	1084	1626	2168
2.1	236	472	708	472	944	1416	1888
5	66	132	198	132	264	396	528
10	8	16	24	16	32	48	64
15	1	2	3	2	4	6	8
LMSA3□(-Z) ~LMSAC□ series attraction force. Unit: N							
Air gap (mm)	LMSA31 LMSA31-Z	LMSA32 LMSA32-Z	LMSA33 LMSA33-Z	LMSA34 LMSA34-Z	LMSAC3	LMSAC5	
0	1959	3918	5877	7836	6367	10611	
0.3	1680	3360	5040	6720	5460	9100	
0.6	1444	2888	4333	5777	4694	7823	
0.9	1245	2490	3735	4980	4046	6744	
1.2	1077	2154	3231	4308	3500	5834	
1.5	936	1872	2808	3744	3042	5070	
1.8	813	1626	2439	3252	2642	4404	
2.1	708	1416	2124	2832	2301	3835	
5	198	396	594	792	644	1073	
10	24	48	72	96	78	130	
15	3	6	9	12	10	16	

3.2.2 LMFA series

■ Continuous force/peak force and air gap: Cover type



■

Figure 3.2-3 LMFA with cover type Continuous force/peak force-air gap relationship graph

Table 3.2-3 LMFA with cover type Continuous force/peak force-air gap comparison chart

LMFA series continuous force/peak force (Cover type). Unit: %		
Air gap (mm)	**LMFA0□~LMFA2□**	**LMFA3□~LMFA6□**
0.1	119	117
0.2	117	114
0.3	114	113
0.4	112	111
0.5	110	109
0.6	107	106
0.7	105	104
0.8	103	102
0.9	100	100
1	98	99
1.1	96	97
1.2	94	95
1.3	92	93
1.4	90	92
1.5	88	90
1.6	86	88
1.7	84	86
1.8	82	85

■ Continuous force/peak force and air gap: Epoxy type

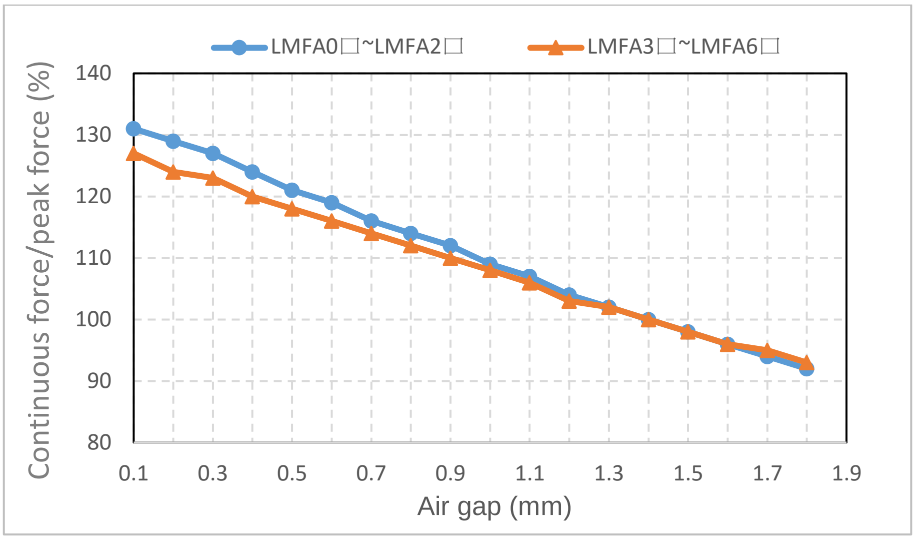


Figure 3.2-4 LMFA with epoxy type Continuous force/peak force-air gap relationship graph

Table 3.2-4 LMFA with epoxy type Continuous force/peak force-air gap comparison chart

LMFA series Continuous force/peak force (Epoxy type). Unit: %		
Air gap (mm)	**LMFA0□~LMFA2□**	**LMFA3□~LMFA6□**
0.1	131	127
0.2	129	124
0.3	127	123
0.4	124	120
0.5	121	118
0.6	119	116
0.7	116	114
0.8	114	112
0.9	112	110
1	109	108
1.1	107	106
1.2	104	103
1.3	102	102
1.4	100	100
1.5	98	98
1.6	96	96
1.7	94	95
1.8	92	93

■ Attraction force and air gap: Cover type

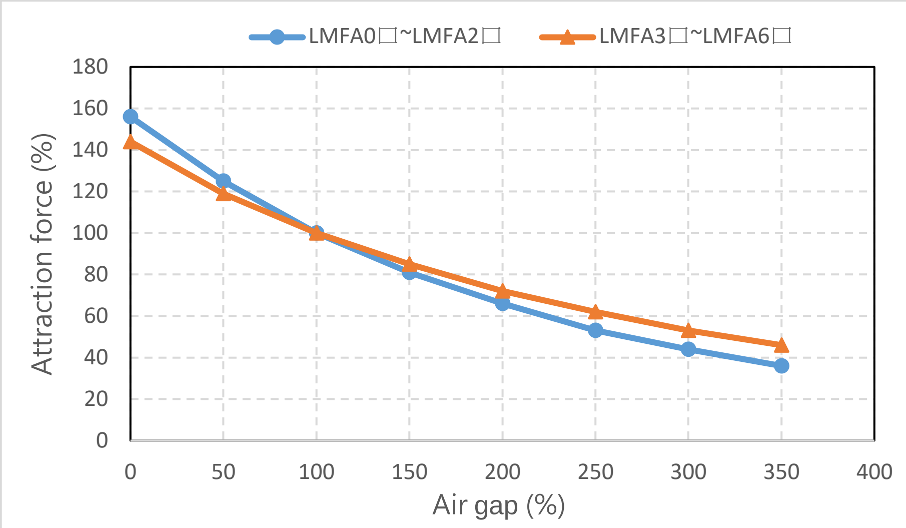


Figure 3.2-5 LMFA with cover type attraction force-air gap relationship graph

Table 3.2-5 LMFA0~2 with cover type attraction force-air gap comparison chart

LMFA0□~LMFA2□ series attraction force (Cover type). Unit: N											
Air gap (mm)	**LMFA01**	**LMFA02**	**LMFA03**	**LMFA11**	**LMFA12**	**LMFA13**	**LMFA14**	**LMFA21**	**LMFA22**	**LMFA23**	**LMFA24**
0	713	1426	2141	1306	2612	3919	5225	1965	3930	5894	7859
0.45	569	1138	1709	1042	2085	3127	4169	1568	3136	4704	6271
0.9	457	914	1372	837	1674	2511	3348	1259	2518	3777	5036
1.35	369	738	1108	676	1352	2029	2705	1017	2034	3051	4068
1.8	299	599	899	548	1097	1645	2194	825	1650	2475	3299
2.25	244	487	731	446	892	1338	1785	671	1342	2013	2684
2.7	199	398	597	364	729	1093	1458	548	1097	1645	2193
3.15	163	325	488	298	595	893	1191	448	896	1343	1791
5	72	145	218	133	266	398	531	200	399	599	799
10	9	17	26	16	32	48	64	24	48	72	96
15	1	3	4	2	5	7	10	4	7	11	15
20	0	0	1	0	1	1	2	1	1	2	2

Table 3.2-6 LMFA3~6 with cover type attraction force-air gap comparison chart

LMFA3□~LMFA4□ series attraction force (Cover type). Unit: N								
Air gap (mm)	**LMFA31**	**LMFA32**	**LMFA33**	**LMFA34**	**LMFA41**	**LMFA42**	**LMFA43**	**LMFA44**
0	4926	9851	14777	19703	7388	14777	22165	29554
0.45	4089	8179	12268	16357	6134	12268	18402	24536
0.9	3430	6860	10290	13720	5145	10290	15435	20580
1.35	2902	5805	8707	11609	4354	8707	13061	17414
1.8	2471	4942	7413	9884	3707	7413	11120	14826
2.25	2117	4234	6351	8468	3176	6351	9527	12703
2.7	1821	3642	5462	7283	2731	5462	8193	10925
3.15	1572	3144	4717	6289	2358	4717	7075	9433
5	885	1770	2655	3539	1327	2655	3982	5309
10	208	417	625	833	312	625	937	1250
15	52	104	156	207	78	156	233	311
20	13	26	40	53	20	40	59	79
LMFA5□~LMFA6□ series attraction force (Cover type). Unit: N								
Air gap (mm)	**LMFA52**	**LMFA53**	**LMFA54**	**LMFA62**	**LMFA63**	**LMFA64**		
0	19674	29511	39348	29554	44331	59108		
0.45	16333	24500	32667	24536	36804	49072		
0.9	13700	20550	27400	20580	30870	41160		
1.35	11593	17389	23185	17414	26121	34828		
1.8	9870	14805	19740	14826	22239	29653		
2.25	8456	12684	16912	12703	19054	25405		
2.7	7272	10909	14545	10925	16387	21849		
3.15	6280	9419	12559	9433	14150	18866		
5	3534	5301	7069	5309	7964	10618		
10	832	1248	1664	1250	1874	2499		
15	207	311	414	311	467	622		
20	53	79	105	79	119	158		

■ Attraction force and air gap: Epoxy type

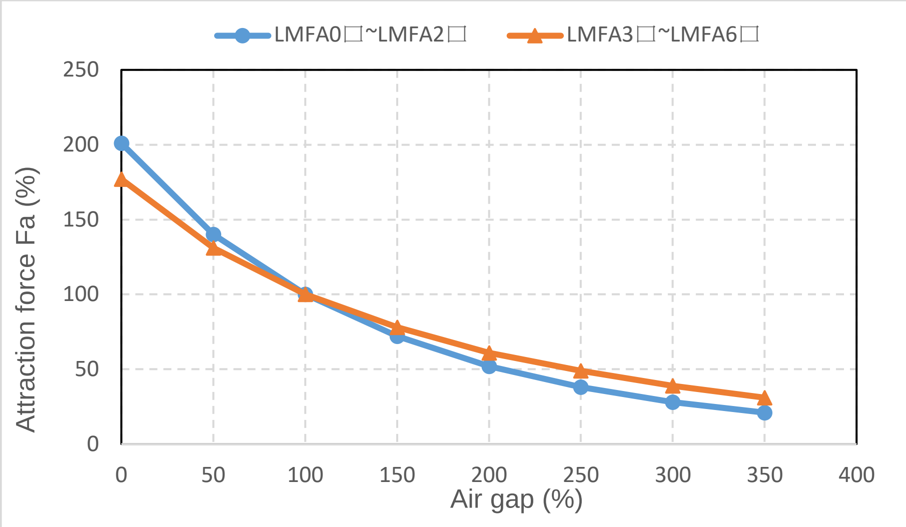


Figure 3.2-6 LMFA with epoxy type attraction force-air gap relationship graph

Table 3.2-7 LMFA0~2 with epoxy type attraction force-air gap comparison chart

LMFA0□~LMFA2□ series attraction force (Epoxy type). Unit: N											
Air gap (mm)	**LMFA01**	**LMFA02**	**LMFA03**	**LMFA11**	**LMFA12**	**LMFA13**	**LMFA14**	**LMFA21**	**LMFA22**	**LMFA23**	**LMFA24**
0	919	1839	2760	1684	3368	5052	6736	2533	5066	7599	10132
0.7	641	1282	1925	1174	2349	3523	4697	1766	3533	5299	7066
1.4	457	914	1372	837	1674	2511	3348	1259	2518	3777	5036
2.1	329	659	988	603	1206	1809	2412	907	1814	2721	3628
2.8	239	478	718	438	876	1314	1752	659	1318	1976	2635
3.5	175	350	525	320	640	960	1280	482	963	1445	1926
4.2	129	257	386	236	472	707	943	355	709	1064	1419
4.9	95	189	284	173	346	520	693	261	521	782	1042
10	11	22	33	20	40	60	79	30	60	90	119
15	1	3	4	3	5	8	11	4	8	12	16
20	0	0	0	0	0	0	0	0	0	0	0

Table 3.2-8 LMFA3~6 with epoxy type attraction force-air gap comparison chart

LMFA3□~LMFA4□ series attraction force (Epoxy type). Unit: N								
Air gap (mm)	**LMFA31**	**LMFA32**	**LMFA33**	**LMFA34**	**LMFA41**	**LMFA42**	**LMFA43**	**LMFA44**
0	6069	12138	18206	24275	9103	18206	27310	36413
0.7	4494	8989	13483	17978	6742	13483	20225	26966
1.4	3430	6860	10290	13720	5145	10290	15435	20580
2.1	2663	5326	7988	10651	3994	7988	11982	15977
2.8	2098	4195	6293	8391	3147	6293	9440	12586
3.5	1665	3330	4995	6660	2497	4995	7492	9989
4.2	1335	2670	4005	5340	2002	4005	6007	8010
4.9	1076	2152	3228	4304	1614	3228	4842	6456
10	245	490	734	979	367	734	1102	1469
15	61	122	184	245	92	184	275	367
20	15	31	46	62	23	46	69	93
30	0	0	0	0	0	0	0	0
LMFA5□~LMFA6□ series attraction force (Epoxy type). Unit: N								
Air gap (mm)	**LMFA52**	**LMFA53**	**LMFA54**	**LMFA62**	**LMFA63**	**LMFA64**		
0	24240	36360	48480	36413	54619	72826		
0.7	17951	26927	35903	26966	40450	53933		
1.4	13700	20550	27400	20580	30870	41160		
2.1	10635	15953	21271	15977	23965	31953		
2.8	8379	12568	16757	12586	18880	25173		
3.5	6650	9975	13300	9989	14984	19979		
4.2	5332	7998	10664	8010	12014	16019		
4.9	4297	6446	8595	6456	9683	12911		
10	978	1467	1956	1469	2203	2938		
15	244	367	489	367	551	734		
20	62	92	123	93	139	185		
30	0	0	0	0	0	0		

3.2.3 LMFP series

■ Continuous force/peak force and air gap: Cover type

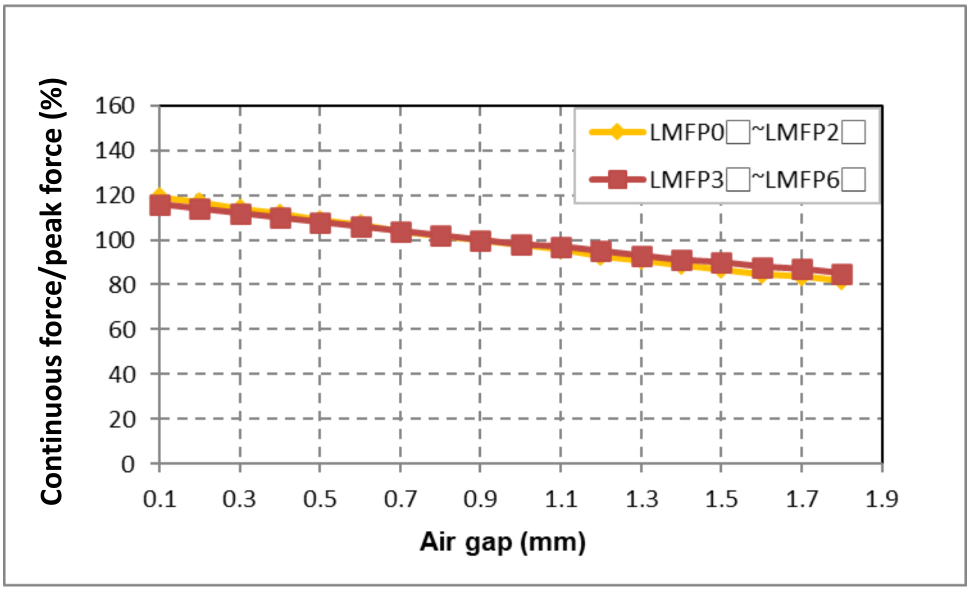


Figure 3.2-7 LMFP with cover type Continuous force/peak force-air gap relationship graph

Table 3.2-9 LMFP with cover type Continuous force/peak force-air gap comparison chart

LMFP series Continuous force/peak force (Cover type). Unit: %		
Air gap (mm)	**LMFP0□~LMFP2□**	**LMFP3□~LMFP6□**
0.1	119	116
0.2	117	114
0.3	114	112
0.4	112	110
0.5	109	108
0.6	107	106
0.7	104	104
0.8	102	102
0.9	100	100
1	98	98
1.1	96	97
1.2	93	95
1.3	91	93
1.4	89	91
1.5	87	90
1.6	85	88
1.7	84	87
1.8	82	85

■ Continuous force/peak force and air gap: Epoxy type

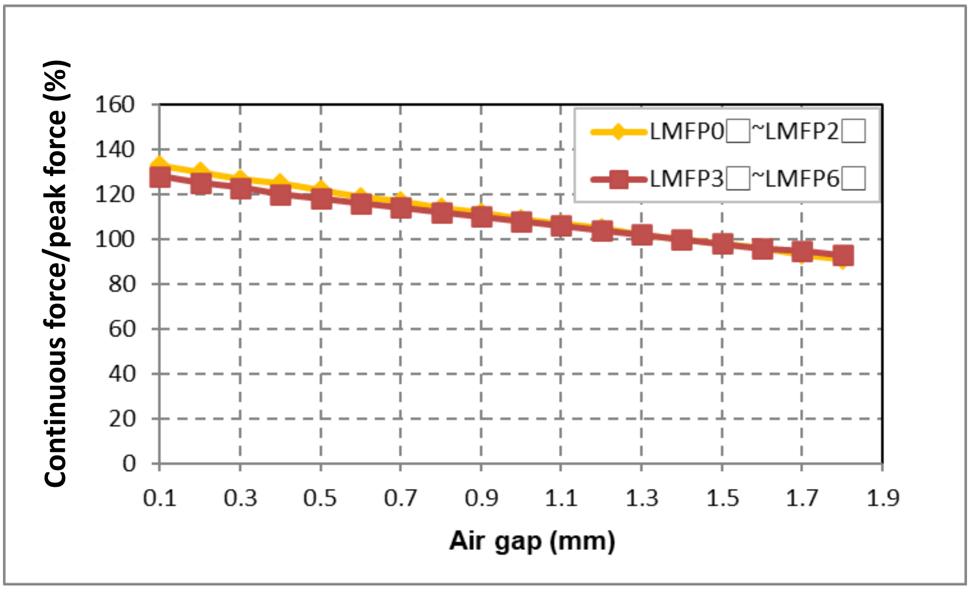


Figure 3.2-8 LMFP with epoxy type Continuous force/peak force-air gap relationship graph

Table 3.2-10 LMFP with epoxy type Continuous force/peak force-air gap comparison chart

LMFP series Continuous force/peak force (Epoxy type). Unit: %		
Air gap (mm)	**LMFP0□~LMFP2□**	**LMFP3□~LMFP6□**
0.1	133	128
0.2	130	125
0.3	127	123
0.4	125	120
0.5	122	118
0.6	119	116
0.7	117	114
0.8	114	112
0.9	112	110
1	109	108
1.1	107	106
1.2	105	104
1.3	102	102
1.4	100	100
1.5	98	98
1.6	96	96
1.7	93	95
1.8	91	93

■ Attraction force and air gap: Cover type

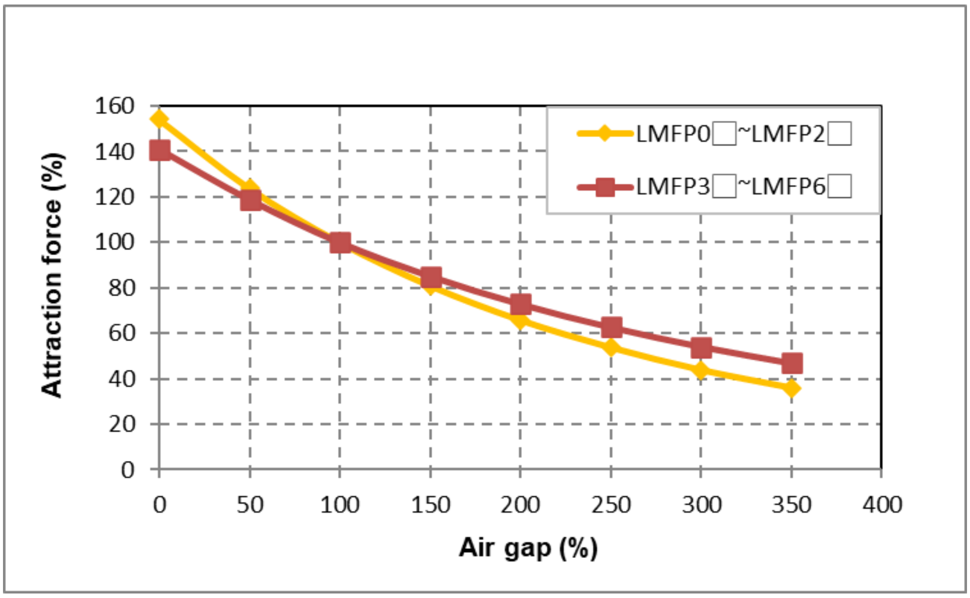


Figure 3.2-9 LMFP with cover type attraction force-air gap relationship graph

Table 3.2-11 LMFP0~2 with cover type attraction force-air gap comparison chart

LMFP0□~LMFP2□ series attraction force (Cover type). Unit: N											
Air gap (mm)	LMFP01	LMFP02	LMFP03	LMFP11	LMFP12	LMFP13	LMFP14	LMFP21	LMFP22	LMFP23	LMFP24
0	641	1282	1925	1174	2348	3523	4697	1766	3533	5299	7065
0.45	515	1030	1546	943	1886	2829	3772	1418	2837	4255	5674
0.9	416	832	1249	762	1523	2285	3047	1146	2291	3437	4583
1.35	337	673	1011	617	1233	1850	2466	927	1855	2782	3710
1.8	274	548	822	501	1003	1504	2006	754	1508	2263	3017
2.25	224	448	672	410	820	1230	1639	616	1233	1849	2466
2.7	183	365	548	335	669	1004	1338	503	1007	1510	2013
3.15	150	300	450	275	549	824	1099	413	827	1240	1653
5	67	134	201	122	245	367	490	184	368	552	737
10	8	16	24	15	29	44	58	22	44	65	87
15	1	2	3	2	4	5	7	3	5	8	11
20	0	0	0	0	0	0	0	0	0	0	0

Table 3.2-12 LMFP3~6 with cover type attraction force-air gap comparison chart

LMFP3□~LMFP4□ series attraction force (Cover type). Unit: N								
Air gap (mm)	**LMFP31**	**LMFP32**	**LMFP33**	**LMFP34**	**LMFP41**	**LMFP42**	**LMFP43**	**LMFP44**
0	4404	8808	13213	17617	6606	13213	19819	26425
0.45	3710	7419	11129	14839	5565	11129	16694	22258
0.9	3121	6243	9364	12485	4682	9364	14046	18728
1.35	2656	5313	7969	10625	3984	7969	11953	15938
1.8	2273	4546	6819	9092	3409	6819	10228	13638
2.25	1955	3910	5864	7819	2932	5864	8797	11729
2.7	1687	3374	5061	6748	2531	5061	7592	10123
3.15	1461	2922	4383	5845	2192	4383	6575	8767
5	828	1657	2485	3313	1243	2485	3728	4970
10	196	393	589	786	295	589	884	1179
15	50	99	149	198	74	149	223	297
20	12	24	37	49	18	37	55	73
LMFP5□~LMFP6□ series attraction force (Cover type). Unit: N								
Air gap (mm)	**LMFP52**	**LMFP53**	**LMFP54**	**LMFP62**	**LMFP63**	**LMFP64**		
0	17591	26387	35183	26425	39638	52851		
0.45	14814	22226	29635	22258	33388	44517		
0.9	12467	18701	24934	18728	28092	37456		
1.35	10610	15914	21219	15938	23906	31875		
1.8	9079	13618	18157	13638	20457	27276		
2.25	7808	11712	15616	11729	17593	23458		
2.7	6739	10108	13477	10123	15184	20245		
3.15	5836	8754	11672	8767	13150	17534		
5	3309	4963	6617	4970	7455	9940		
10	785	1177	1569	1179	1768	2357		
15	198	297	396	297	446	595		
20	49	73	97	73	110	146		

■ Attraction force and air gap: Epoxy type

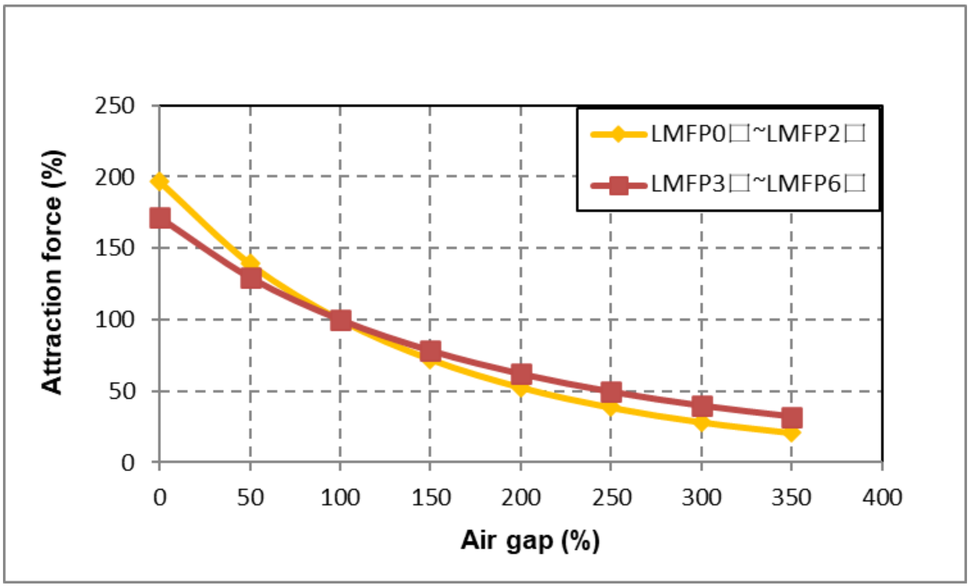


Figure 3.2-10 LMFP with epoxy type attraction force-air gap relationship graph

Table 3.2-13 LMFP0~2 with epoxy type attraction force-air gap comparison chart

LMFP0□~LMFP2□ series attraction force (Epoxy type). Unit: N											
Air gap (mm)	LMFP01	LMFP02	LMFP03	LMFP11	LMFP12	LMFP13	LMFP14	LMFP21	LMFP22	LMFP23	LMFP24
0	818	1637	2457	1499	2996	4495	5994	2255	4507	6762	9016
0.7	579	1158	1739	1061	2120	3181	4242	1595	3189	4785	6380
1.4	416	832	1249	762	1523	2285	3047	1146	2291	3437	4583
2.1	301	603	905	552	1103	1655	2207	830	1659	2489	3319
2.8	220	439	660	402	804	1207	1609	605	1210	1815	2420
3.5	161	322	483	295	589	884	1179	443	886	1330	1773
4.2	119	237	356	217	434	651	868	327	653	979	1306
4.9	88	175	263	160	321	481	641	241	482	723	965
10	10	21	31	19	38	57	76	28	57	85	114
15	2	3	5	3	6	9	12	4	9	13	18
20	0	0	0	0	0	0	0	0	0	0	0

Table 3.2-14 LMFP3~6 with epoxy type attraction force-air gap comparison chart

LMFP3□~LMFP4□ series attraction force (Epoxy type). Unit: N								
Air gap (mm)	**LMFP31**	**LMFP32**	**LMFP33**	**LMFP34**	**LMFP41**	**LMFP42**	**LMFP43**	**LMFP44**
0	5355	10713	16068	21424	8034	16068	24102	32136
0.7	4044	8089	12133	16177	6067	12133	18200	24266
1.4	3121	6243	9364	12485	4682	9364	14046	18728
2.1	2444	4888	7332	9776	3666	7332	10998	14664
2.8	1936	3872	5807	7743	2904	5807	8711	11615
3.5	1545	3091	4636	6181	2318	4636	6954	9272
4.2	1241	2483	3725	4966	1862	3725	5587	7450
4.9	1004	2009	3013	4017	1506	3013	4519	6026
10	974	1949	2923	3898	1462	2923	4385	5847
15	230	460	689	919	345	689	1034	1379
20	57	114	171	228	85	171	256	342
30	15	30	45	60	22	45	67	90
LMFP5□~LMFP6□ series attraction force (Epoxy type). Unit: N								
Air gap (mm)	**LMFP52**	**LMFP53**	**LMFP54**	**LMFP62**	**LMFP63**	**LMFP64**		
0	21393	32090	42786	32136	448205	64273		
0.7	16154	24231	32307	24266	36399	48532		
1.4	12467	18701	24934	18728	28092	37456		
2.1	9762	14643	19523	14664	21996	29328		
2.8	7732	11598	15463	11615	17422	23229		
3.5	6172	9258	12344	9272	13907	18543		
4.2	4959	7439	9918	7450	11175	14899		
4.9	4011	6017	8023	6026	9039	12052		
10	3892	5838	7784	5847	8770	11693		
15	918	1377	1836	1379	2068	2758		
20	228	341	455	342	513	684		
30	60	90	119	90	135	179		

3.2.4 LMSC series

■ Attraction force and air gap

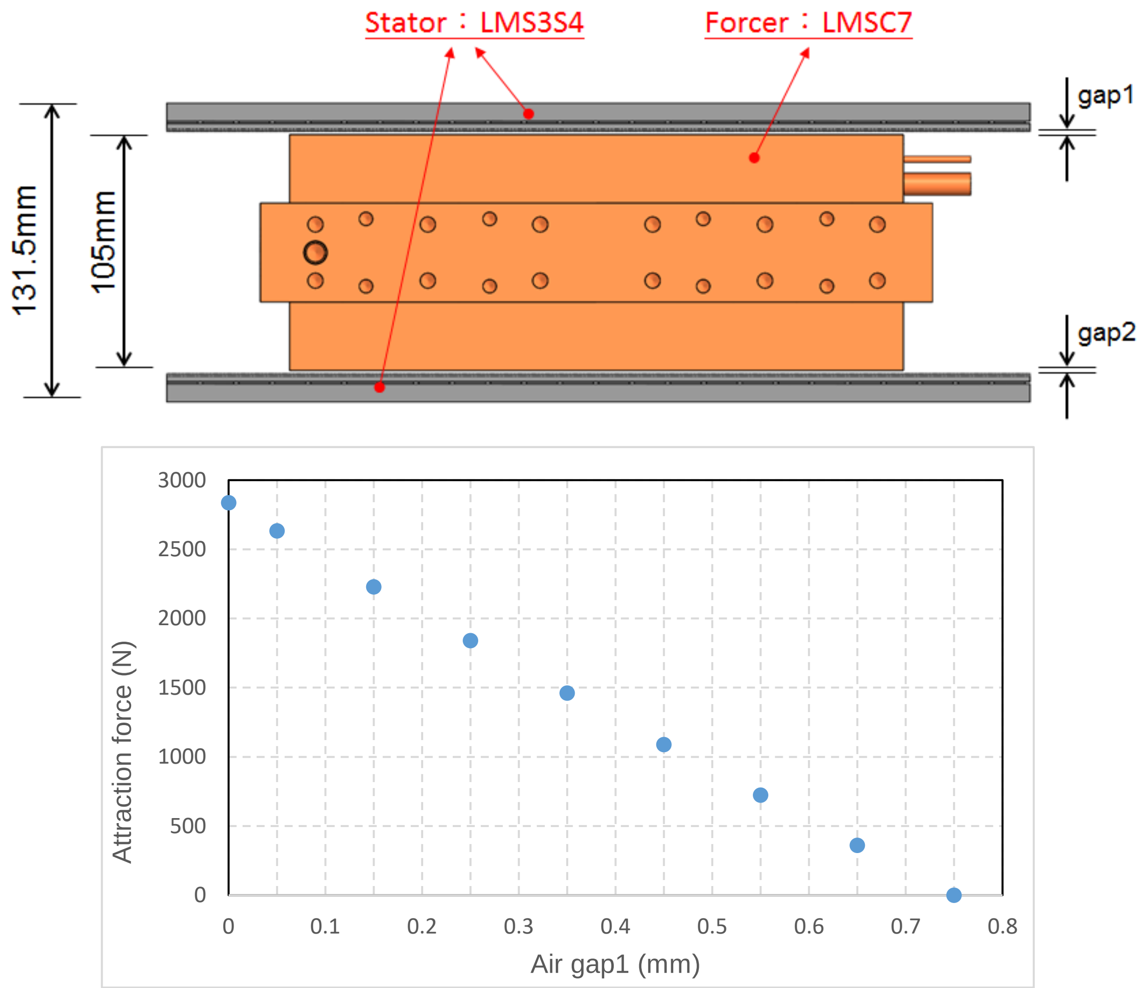


Figure 3.2-11 LMSC attraction force-air gap relationship graph

Table 3.2-15 LMSC attraction force-air gap comparison chart

Series	**LMSC7(L) (WC)**								
Air gap 1 (mm)	0	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75
Air gap 2 (mm)	1.5	1.45	1.35	1.25	1.15	1.05	0.95	0.85	0.75
Attracting force (N)	2838	2633	2230	1840	1464	1090	724	361	0

3.3 Environmental temperature and Continuous force

HIWIN linear motor Continuous force is defined based on the Maximum winding temperature of such series motors reached under the environmental temperature of 25℃. When the operating environmental temperature exceeds 25℃, the Continuous force achievable by the motor is reduced. Under different environmental temperatures, the Continuous force that can be achieved without having the motor exceeding the Maximum winding temperature under different environmental temperatures can be calculated from the following formula.

$$\frac{T_{max} - T_{amb}}{T_{max} - T_0} = \frac{{F_x}^2}{{F_C}^2}$$

T_{max}: Maximum winding temperature (catalog value) [℃]
T_{amb}: Environmental temperature [℃]
T_0: Motor initial temperature [℃], water-cooling T_0=20℃, natural-cooling T_0=25℃
F_C: Continuous force (catalog value) [N]
F_x: Achievable Continuous force under different environmental temperatures [N]

The relationship between different environmental temperatures and achievable Continuous force is as shown in Figure 3.3-1 and Figure 3.3-2

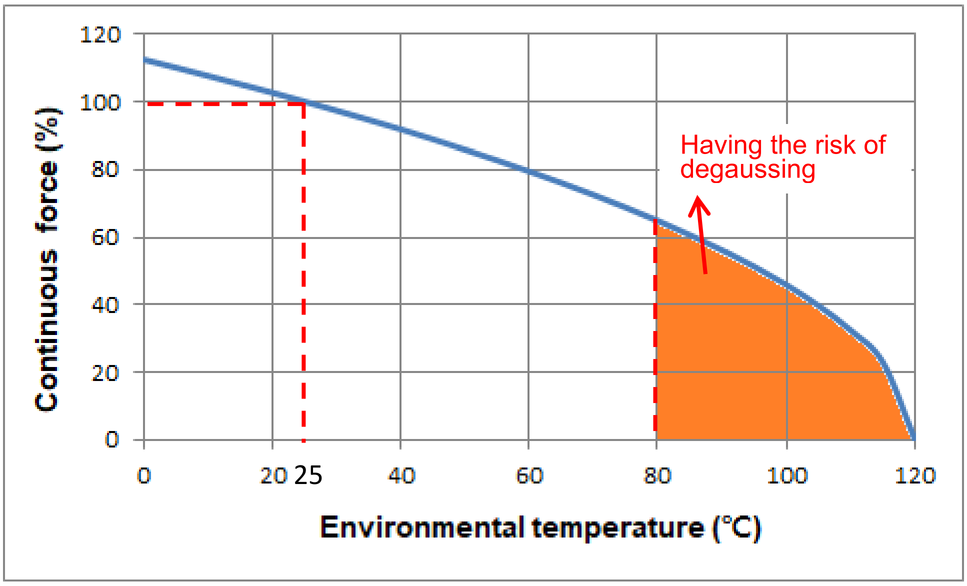


Figure 3.3-1 Environmental temperature v.s. Continuous force relationship graph with natural-cooling motor

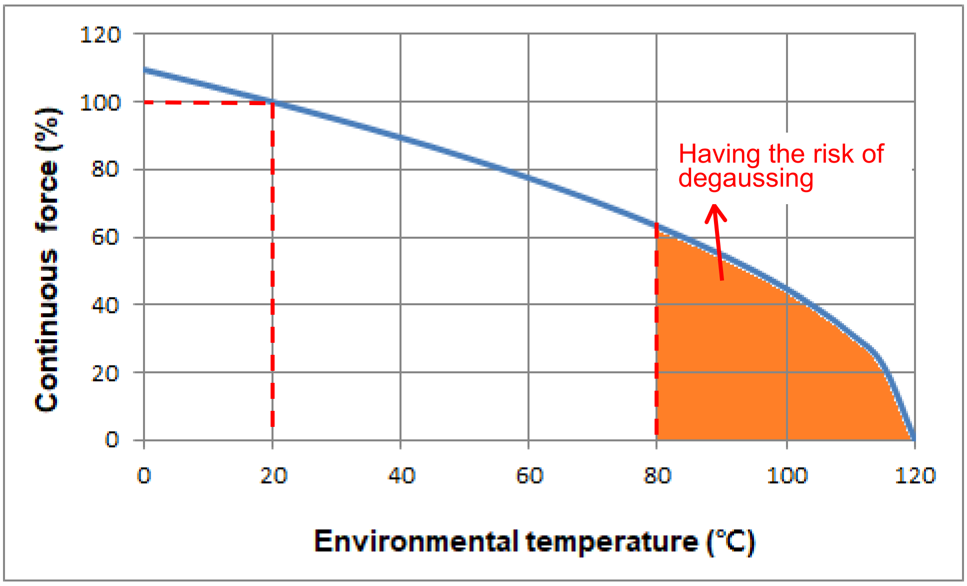


Figure 3.3-2 Environmental temperature v.s. Continuous force relationship graph with water-cooling motor

3.4 Motor heat calculation

3.4.1 Motor heat loss

During the process of converting electrical energy into kinetic energy of a motor, it is inevitable that copper loss, iron loss and mechanical loss also occur; where copper loss refers to the loss caused by the resistance as current passes through the motor forcer coil; iron loss is caused by the magnetic field conversion between the forcer and stator magnets; and mechanical loss is, in general, far less than the copper and iron losses such that it can be omitted.

The copper loss calculation method under the Continuous force is:

$$P_C = \frac{3}{2} \times R_{25} \times \{1 + [0.00393 \times (T_{max} - 25)]\} \times {I_C}^2$$

P_C: Copper loss when the coil temperature is T_{max} [W]
R_{25}: Line-to-line resistance when the coil temperature is 25℃ [Ω]
I_c: Continuous current when the coil temperature is T_{max} [A_{rms}]
T_{max} : Maximum winding temperature [℃] (please refer to the catalog of each series motor)

Heat loss mainly utilizes the thermal conduction method to transfer the loss of the coil to the motor surface. In an example of natural air cooling, the heat loss source is transferred to the external environment via heat convection from the motor surface in contact with the air, and the heat is further transferred away through heat radiation and thermal conduction from the installation surface of customers. In an example of water-cooling, the heat loss source utilizes thermal conduction to transfer heat from the heat source center to the cooling water, and since cooling water has a heat convection coefficient much higher than that of air, the effect of heat transfer from the heat source to the air via convection can be omitted. The cooling method for LMFA series motors can use the water-cooling or air-cooling type. Please ensure that the parameters used are the same as the ones indicated in the specification, and please also be aware that the Maximum winding temperature shall not exceed 120℃.

3.4.2 Continuous operating temperature

The motor coil steady-state temperature is defined based on the ratio of copper and iron losses. When a linear motor is used, iron loss can be omitted. The motor total loss and rated Continuous force (F_c) are both defined according to the Maximum winding temperature specified in the catalog. When an equivalent thrust force (F_e) is smaller than the rated Continuous force (F_c), the steady-state temperatures of the motor coil under different operational conditions can be obtained from the following formula.
When the operating current is lower than the rated current (l_e ≤ l_c), its relationship between temperature and thrust force is

$$T_e = T_{amb} + \left(\frac{F_e}{F_C}\right)^2 \times (T_{max} - 25)$$

T_e: Coil steady-state temperature under equivalent thrust force [℃]
T_{amb}: Environmental temperature [℃]
F_e: Equivalent thrust force of actual operation [N] (when coil temperature is T_e)
F_c: Rated Continuous force [N] (when the coil temperature is T_{max})

3.4.3 Thermal time constant

During the operating process of a motor, its coil temperature is related to the thermal time constant. The thermal time constant is defined to be the time (as shown in Figure 3.4-1) when the temperature difference between the coil initial temperature T_0 and the Maximum winding temperature T_{max} reached is 63%. The time for the motor to reach the steady state is approximately 5 times the thermal time constantt_{Th}.

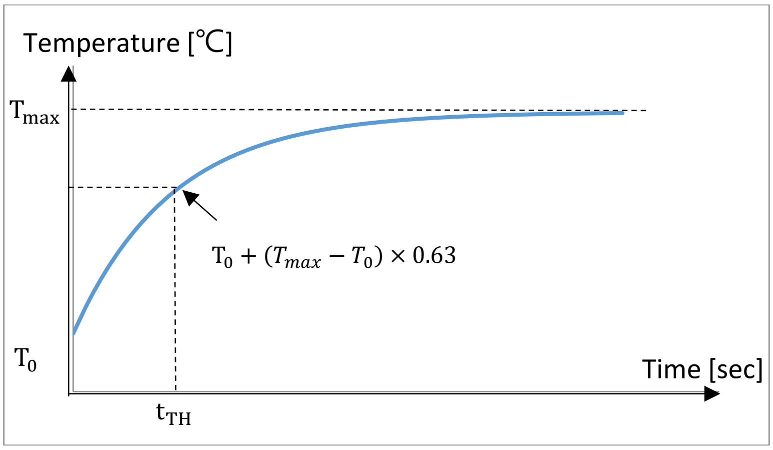


Figure 3.4-1 Motor temperature increase curve graph

The equation between the thermal time constant and temperature is

$$T(t) = T_0 + (T_{max} - T_0) \times \left(1 - e^{-\left(\frac{t}{t_{TH}}\right)}\right)$$

$T(t)$: Coil temperature [℃] (at operating time t)
T_0: Coil initial temperature [℃]
T_{max}: Maximum winding temperature [℃]
t_{TH}: Thermal time constant [sec] (please refer to catalog for each series motor)
t: Operating time [sec]

When the operating current is between the rated current and peak current (l_c < l_e < l_p), it is necessary to set up the power off idleness time to allow the motor to cool down. In addition, the aforementioned thermal time constant can be used for calculating the time required for the load cycle. First, according to Section 3.4.3, the equivalent thrust force of actual operation (F_e) is used to obtain the coil steady-state temperature (T_e) value under the equivalent thrust force, following which the following equation is then used to obtain the relative maximum operating time.

The equation for the coil steady-state temperature (T_e) under the equivalent thrust force and the maximum operating time is

$$t = -t_{TH} \times \ln\left(1 - \frac{T_e - T_0}{T_{max} - T_0}\right)$$

t: Maximum operating time [sec]

NOTE The coil temperature (T_e) of the equivalent current described here shall not exceed the Maximum winding temperature (T_{max}) specified in the catalog.

3.5 Cooling system calculation

⚠ WARNING!

Risk of working temperature.

When incorrectly operated and in the case of a fault, the motor can overheat resulting in fire and smoke. This can result in severe injury or death. Further, excessively high temperatures destroy motor components and result in increased failures as well as shorter service lives of motors

- Operate the motor according to the relevant specifications.
- Allow the forcer to cool down sufficiently (in a 25°C room temperature) before working around the product to avoid burns.
- When an abnormal smell, noise, smoke, or vibration is detected, please turn off the power immediately.

The motor cooling system mainly utilizes the motor Maximum dissipated heat output, minimum flow rate of coolant, pressure difference between coolant inlet and an outlet and the temperature difference between the coolant inlet and outlet for calculation. During operation, performing design and selection of a cooling system according to the catalog value is able to allow the motor to achieve optimal performance. If the equivalent thrust force of the motor actual operation is lower than the Continuous force indicated in the catalog, under the condition where the motor is permitted to operate at a higher temperature (but not exceeding the Maximum winding temperature of 120℃), its coolant flow rate may be reduced lower to prevent excessive consumption of pumping work. The cooling condition can be adjusted appropriately according to the following formula.

The following formula can be used to adjust the water-cooling system boundary condition according to different motor power losses: Under the user's operational condition where the equivalent thrust force is smaller than the Continuous force (F_e<F_c), to determine the coolant flow rate required to be adjusted at the customer end, the following equation can be used to solve the coolant flow rate corresponding to the equivalent thrust force.

$$Q_{P,H,e} = \frac{Q_{P,H,MAX}}{(F_c/F_e)^2}$$

$$Q_{P,H,e} = 69.7 \times q_e \times \Delta T$$

where

$Q_{P,H,e}$: Motor total loss under the equivalent thrust force [W]

$Q_{P,H,MAX}$: Maximum dissipated heat output [W]

ΔT : Temperature difference between inlet and outlet [℃]

q_e: Coolant flow rate under the equivalent thrust force [L/min]

F_c : Continuous force (catalog value) [N]

F_e : Equivalent thrust force of actual operation [N]

The relationship between the coolant flow rate and the temperature difference of inlet and outlet is as shown in Figure 3.5-1, and the relationship between the pressure difference of inlet and outlet and the flow rate is as shown in Figure 3.5-2.

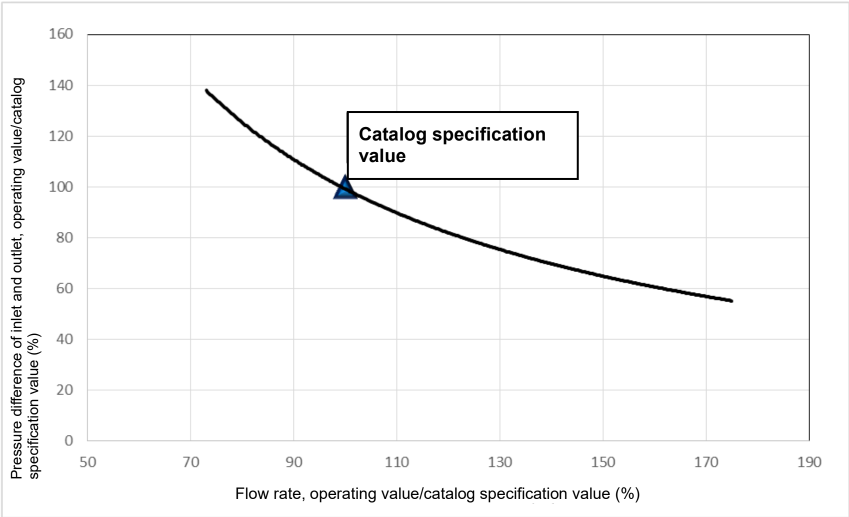


Figure 3.5-1 Coolant flow rate and temperature difference of inlet and outlet relationship graph

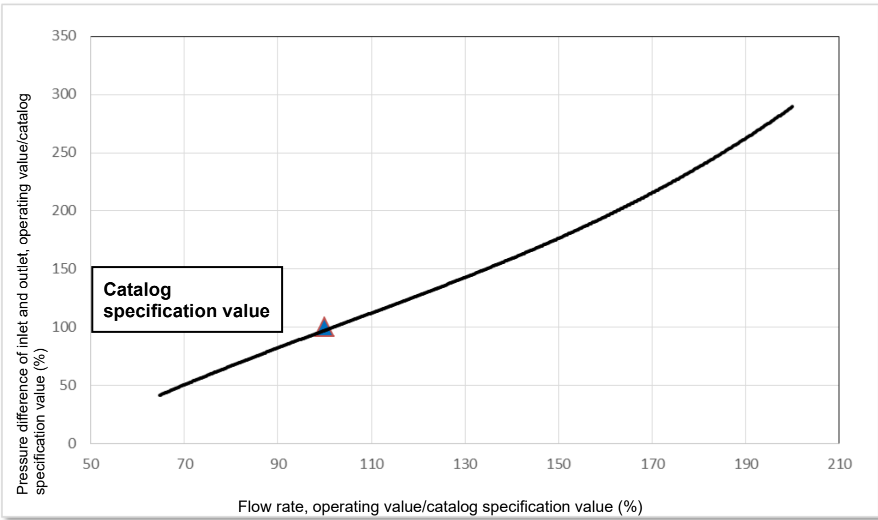


Figure 3.5-2 Pressure difference of inlet and outlet and flow rate relationship graph

3.6 Cooling machine selection

For the selection of a cooling machine, in addition to the consideration of the use scope of the power source and coolant, it mainly refers to the selection of the cooling power and flow rate. It is recommended to select a cooling machine capable of allowing the motor to achieve maximum performance according to the catalog value, or the calculation value of the cooling system described in Section 3.5 can be used as a reference for the selection.

3.6.1 Cooling power selection

The following provides an example. If two linear motors of LMFA31 are used, and the **Maximum dissipated heat output** indicated in the catalog specification is 324 (W), then the sum of the Maximum dissipated heat output of the two motors is 2x324=648 (W). By using the cooling machine of than the motor Maximum dissipated heat output of 648 (W) as an example, under 50Hz, the cooling capacity is 980 (W), which is greater.

LMFA3 series specification	Symbol	Unit	LMFA31	LMFA31L
Continuous force	F_c	N	380	380
Continuous Current	I_c	A(rms)	3.1	4.6
Continuous force (WC)	F_c(wc)	N	759	759
Continuous current (WC)	I_c(wc)	A(rms)	6.2	9.1
Peak force (1 second)	F_p	N	1750	1750
Peak current (1 second)	Ip	A(rms)	19.2	28.3
Force constant	Kf	N/A(rms)	122.7	83.1
Attraction force	Fa	N	3430	3430
Maximum winding temperature	T_{max}	℃	120℃	
Electrical time constant	K_e	ms	11.3	11.4
Resistance (line-to-line, 25℃)	R_{25}	Ω	4.3	1.9
Resistance (line-to-line, 120℃)	R_{120}	Ω	5.6	2.6
Inductance (line-to-line)	L	mH	48.3	22.2
Pole pair distance	2τ	mm	46	
Back EMF constant (line-to-line)	K_v	Vrms(m/s)	70.9	48.0
Motor constant (25℃)	K_m	N/√W	48.4	48.7
Thermal resistance	R_{th}	℃/W	1.17	1.19
Thermal resistance (WC)	R_{th}(wc)	℃/W	0.29	0.30
Minimum flow rate	-	L/min	4.0	4.0
Temperature of cooling water	-	℃	20	
Thermal sensor switch	-		1xKTY84-130+1x(3PTC SNM120 In Series)	
Maximum speed of Peak force	$V_{max,Fmax}$	m/s	4.08	6.19
Maximum output power	PEL,MAX	W	10255	13910
Maximum dissipated heat output	$Q_{P,H,MAX}$	W	324	320
Locked-rotor torque (water-cooling)	F_e	N	531	531
Stall current (water-cooling)	I0	A(rms)	4.3	6.4

<table>
<tr><td rowspan="3">Cooling capacity</td><td>KCAL/H 50/60Hz</td><td>450/500</td><td>840/1000</td><td>1400/1500</td><td>1700/2100</td><td>2600/3000</td><td>3200/3800</td></tr>
<tr><td>W 50/60Hz</td><td>525/580</td><td>980/1170</td><td>1630/1750</td><td>1980/2450</td><td>2900/3500</td><td>3700/4400</td></tr>
<tr><td>BTU/H 50/60Hz</td><td>1800/2000</td><td>3360/ 4000</td><td>5600/6000</td><td>6800/8400</td><td>10000/12000</td><td>12800/15200</td></tr>
<tr><td rowspan="2">Temperature control</td><td>A</td><td colspan="6">Fixed type (setting range of 10~40℃)</td></tr>
<tr><td>B</td><td colspan="6">Temperature difference type/machine body temperature tracking type, setting range of -10 ~ +10℃)</td></tr>
<tr><td rowspan="2">Scope of use</td><td>Room temperature</td><td colspan="6">10 ~ 40℃</td></tr>
<tr><td>Oil temperature</td><td colspan="6">10 ~ 30℃</td></tr>
<tr><td colspan="2">Power</td><td colspan="6">3φ200~230V 50/60Hz</td></tr>
<tr><td rowspan="3">Motor (W)</td><td>Compressor</td><td colspan="3">460</td><td>740</td><td>1135</td><td>1450</td></tr>
<tr><td>Fan</td><td>56</td><td>50</td><td colspan="2">95</td><td colspan="2">180</td></tr>
<tr><td>Pump</td><td>120</td><td colspan="5">750</td></tr>
<tr><td rowspan="2">Pump flow (L/min)</td><td>50Hz</td><td>2</td><td colspan="5">40</td></tr>
<tr><td>60Hz</td><td>3.5</td><td colspan="5">50</td></tr>
</table>

Table 3.6-1 Cooling machine power selection

3.6.2 Flow rate selection

When the cooling machine is under the selected frequency (50/60Hz), the pump flow rate shall be greater than the sum of the motor minimum flow rate, and the pressure generated by the pump flow rate shall be greater than the sum of the pressure drop of the motor internal cooling loop. If the cooling loop of large equipment is longer, then it is necessary to consider the pressure drop caused by the loop pipe resistance.

The following provides an example. If two linear motors of LMFA31 are used, and the **minimum flow rate** indicated in the catalog specification is 4.0 (L/min), then the sum of the minimum flow rate of the two motors is 2x4.0=8.0 (L/min). By using the cooling machine of Table 3.6-2 as an example, the pump flow rate at 50 Hz is 40 (L/min), which is greater than the motor minimum flow rate of 8.0 (L/min).

LMFA3 series specification	Symbol	Unit	LMFA31	LMFA31L
Continuous force	Fc	N	380	380
Continuous Current	Ic	A(rms)	3.1	4.6
Continuous force (WC)	Fc(wc)	N	759	759
Continuous current (WC)	Ic(wc)	A(rms)	6.2	9.1
Peak force (1 second)	Fp	N	1750	1750
Peak current (1 second)	Ip	A(rms)	19.2	28.3
Force constant	Kf	N/A(rms)	122.7	83.1
Attraction force	Fa	N	3430	3430
Maximum winding temperature	Tmax	℃	120℃	
Electrical time constant	Ke	ms	11.3	11.4
Resistance (line-to-line, 25℃)	R_{25}	Ω	4.3	1.9
Resistance (line-to-line, 120℃)	R_{120}	Ω	5.6	2.6
Inductance (line-to-line)	L	mH	48.3	22.2
Pole pair distance	2τ	mm	46	
Back EMF constant (line-to-line)	Kv	Vrms(m/s)	70.9	48.0
Motor constant (25℃)	Km	N/√W	48.4	48.7
Thermal resistance	Rth	℃/W	1.17	1.19
Thermal resistance (WC)	Rth(wc)	℃/W	0.29	0.30
Minimum flow rate	-	L/min	4.0	4.0
Temperature of cooling water	-	℃	20	
Thermal sensor switch	-		1xKTY84-130+1x(3PTC SNM120 In Series)	
Maximum speed of Peak force	Vmax,Fmax	m/s	4.08	6.19
Maximum output power	PEL,MAX	W	10255	13910
Maximum dissipated heat output	$Q_{P,H,MAX}$	W	324	320
Locked-rotor torque (water-cooling)	Fe	N	531	531
Stall current (water-cooling)	I0	A(rms)	4.3	6.4

Cooling capacity	KCAL/H 50/60Hz	450/500	840/1000	1400/1500	1700/2100	2600/3000	3200/3800
	W 50/60Hz	525/580	980/1170	1630/1750	1980/2450	2900/3500	3700/4400
	BTU/H 50/60Hz	1800/2000	3360/4000	5600/6000	6800/8400	10000/12000	12800/15200
Temperature control	A	Fixed type (setting range of 10~40℃)					
	B	Temperature difference type/machine body temperature tracking type, setting range of -10 ~ +10℃)					
Scope of use	Room temperature	10 ~ 40℃					
	Oil temperature	10 ~ 30℃					
Power		3φ200~230V 50/60Hz					
Motor (W)	Compressor	460			740	1135	1450
	Fan	56	50	95		180	
	Pump	120	750				
Pump flow (L/min)	50Hz	2	40				
	60Hz	3.5	50				

Table 3.6-2 Cooling machine flow rate selection

The above briefly describes the selection of a cooling machine. For any questions on the selection of a cooling machine, it is recommended to provide the above information to a cooling machine manufacturer for further discussion.

4. Motor Mechanical Interface

4.1 Iron core linear motor assembly interface

Observe dimension of the gap between forcer and stator after assembly. It will impact linear motor performance and reliability. A well-designed positioning stage and proper tolerance value will improve the stability of products. The sectional view of typical linear motor stage base and the suggested tolerance value are shown as below. The flatness of the installation interface with stator should be 0.02mm per 300mm (as Figure 4.1-1shows).

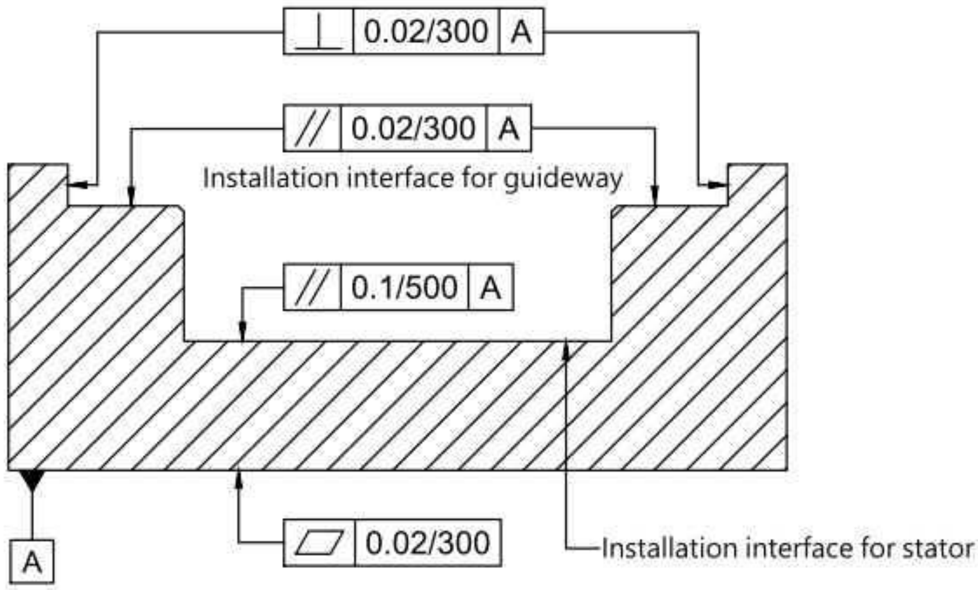


Figure 4.1-1 Sectional view of base design

Observe the assembly total height H and the air gap dimensions between the forcer and stator G after assembly, they will impact the linear motor performance and reliability (please refer to the air gap specification of each series motor). There are two types of stators: stainless cover version and epoxy version.

Forcer and stator of an iron-core linear motor have an immense magnetic attraction with each other (refer to linear motor catalog F_a of each series for the attraction value). Hence, when designing the installation interfaces of both forcer and stator, we must consider and compute the deformation due to the attraction to ensure the height of the total composition H and air gap between the forcer and stator G can be maintained. Should there be any circumstance of a bad air gap G caused by structural deformation, or interferential damage of forcer and stator, HIWIN shall not be responsible for repairs or adjustments free of charge.

4.1.1 LMSA iron core linear motor series

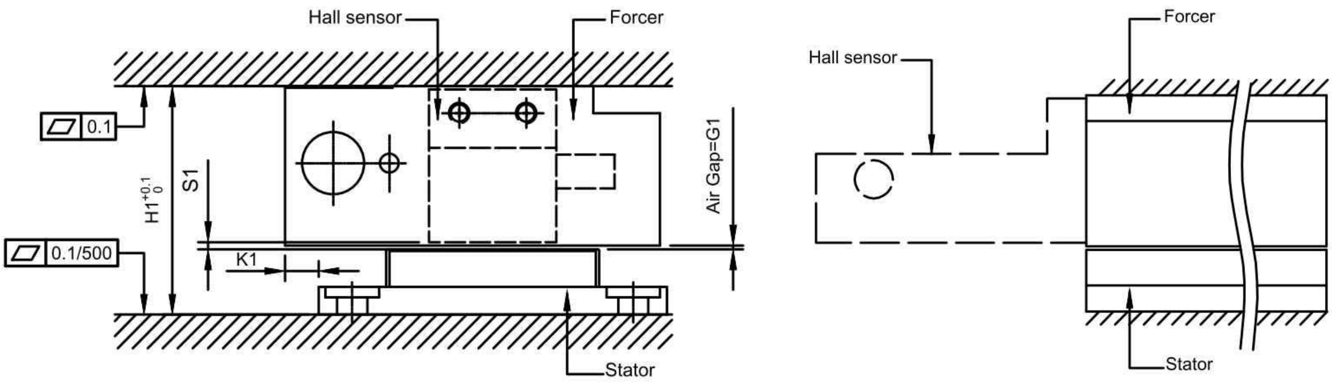


Figure 4.1-2 LMSA iron core linear motor assembly

Table 4.1-1 LMSA iron core linear motor assembly dimensions

Model	Dimensions (mm)				
	H1	K	G1		S1
			Stainless cover	Epoxy	Stainless cover/Epoxy
LMSA1□ LMSA1□-Z	34	5	0.6 +0.35/-0.25	0.6 ±0.25	1 ±0.2
LMSA2□ LMSA2□-Z	34	3			
LMSA3□ LMSA3□-Z	36	3			
LMSAC□	36	1.75			

NOTE S1 is the gap between Hall sensor and stator after motor assembly.

4.1.2 LMFA water-cooling linear motor series

NOTE The precision water-cooling installation dimensions are not included.

NOTE When measure the width of Forcer, since the epoxy could expand or contract with temperature changes, as below pictures

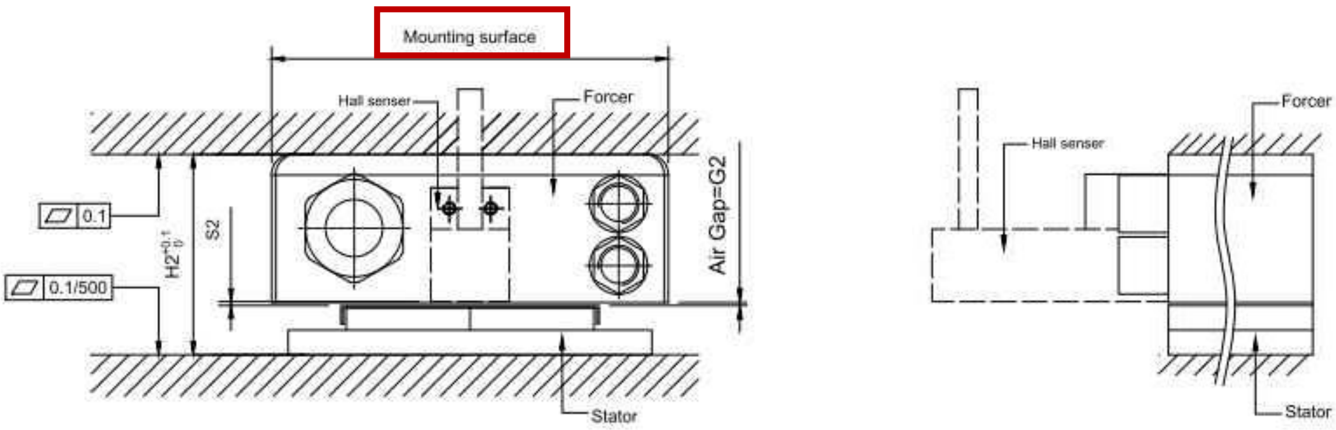


Figure 4.1-3 LMFA water-cooling linear motor assembly

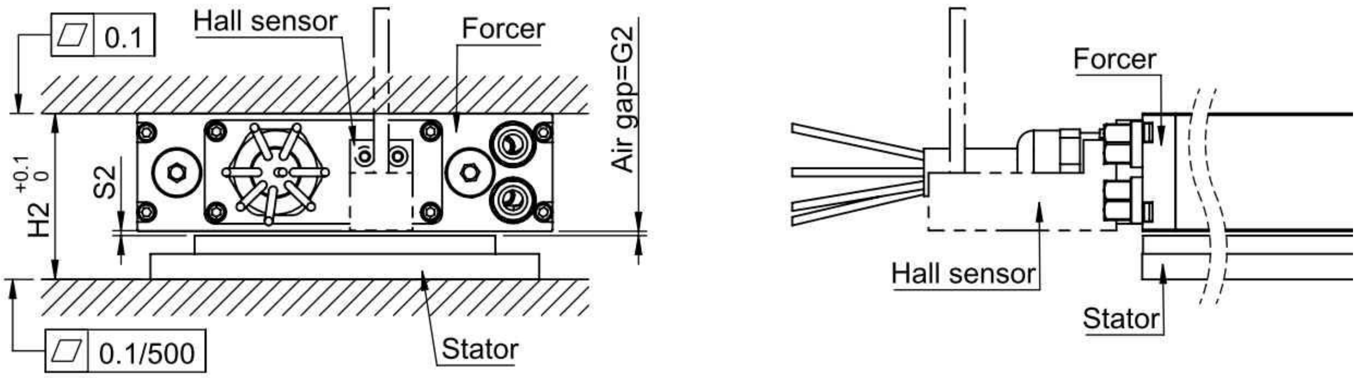


Figure 4.1-4 LMFP water-cooling linear motor assembly

Table 4.1-2 LMFA/LMFP water-cooling linear motor assembly dimensions

<table>
<tr><th rowspan="3">Model</th><th colspan="5">Dimensions (mm)</th></tr>
<tr><th rowspan="2">H2</th><th colspan="2">G2</th><th colspan="2">S2</th></tr>
<tr><th>Stainless cover</th><th>Epoxy</th><th>Stainless cover</th><th>Epoxy</th></tr>
<tr><td>LMFA0□</td><td>48.5</td><td rowspan="5">0.9 ±0.2</td><td rowspan="7">1.4 ±0.2</td><td rowspan="5">1.1 ±0.2</td><td rowspan="7">1.4 ±0.2</td></tr>
<tr><td>LMFA1□</td><td>48.5</td></tr>
<tr><td>LMFA2□/LMFP2□</td><td>50.5</td></tr>
<tr><td>LMFA3□/LMFP3□</td><td>64.1</td></tr>
<tr><td>LMFA4□/LMFP4□</td><td>66.1</td></tr>
<tr><td>LMFA5□/LMFP5□</td><td>64.1</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>LMFA6□/LMFP6□</td><td>66.1</td></tr>
</table>

NOTE S2 is the gap between Hall sensor and stator after motor assembly.

NOTE The LMFC precision water-cooling installation dimensions are included.

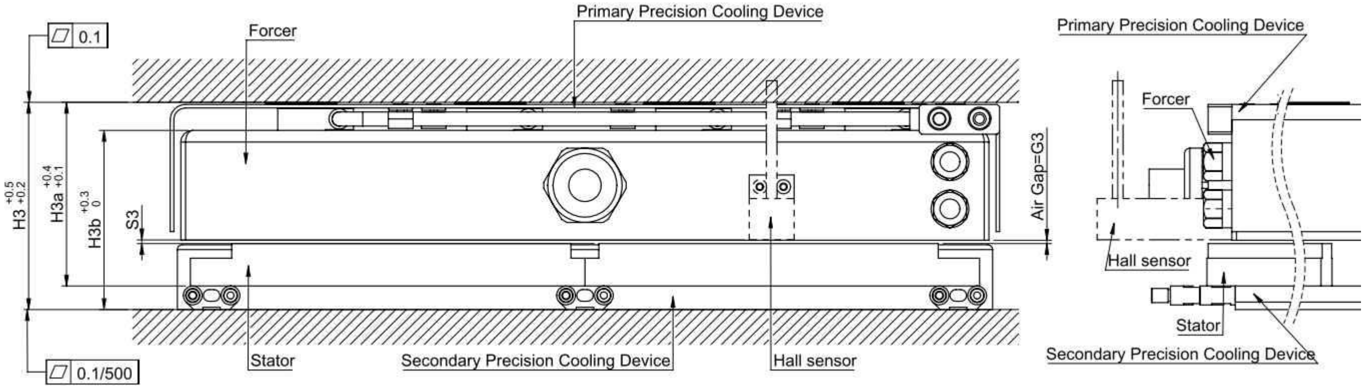


Figure 4.1-5 LMFA precision water-cooling linear motor assembly

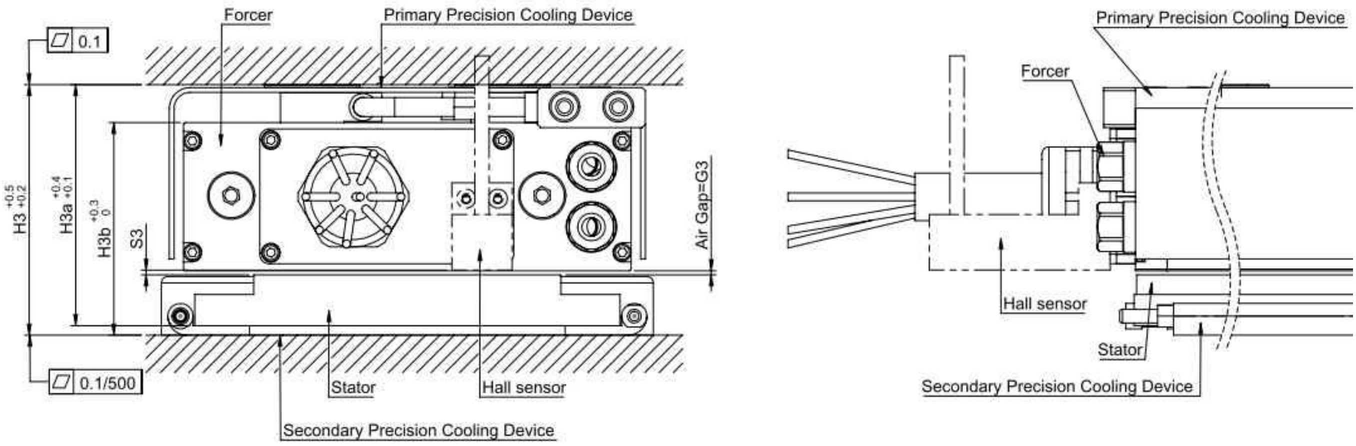


Figure 4.1-6 LMFP precision water-cooling linear motor assembly

Table 4.1-3 LMFA/LMFP precision water-cooling linear motor assembly dimensions

<table>
<tr><th rowspan="3">Model</th><th colspan="7">Dimensions (mm)</th></tr>
<tr><th rowspan="2">H3</th><th rowspan="2">H3a</th><th rowspan="2">H3b</th><th colspan="2">G3</th><th colspan="2">S3</th></tr>
<tr><th>Stainless cover</th><th>Epoxy</th><th>Stainless cover</th><th>Epoxy</th></tr>
<tr><td>LMFA0□</td><td colspan="5" rowspan="3"></td><td rowspan="5">1.1 ±0.2</td><td rowspan="7">1.4 ±0.2</td></tr>
<tr><td>LMFA1□</td></tr>
<tr><td>LMFA2□</td></tr>
<tr><td>LMFA3□/LMFP3□</td><td>79.0</td><td>76</td><td>67.1</td><td rowspan="4">0.9 ±0.5</td><td rowspan="4">1.4 ±0.5</td></tr>
<tr><td>LMFA4□/LMFP4□</td><td>81.0</td><td>78</td><td>69.1</td></tr>
<tr><td>LMFA5□/LMFP5□</td><td>86.0</td><td>76</td><td>74.1</td><td rowspan="2"></td></tr>
<tr><td>LMFA6□/LMFP6□</td><td>88.0</td><td>78</td><td>76.1</td></tr>
</table>

NOTE H3：Contain forcer, stator, precision cooling device system for the forcer and stator.

NOTE H3a：Contain forcer, stator and precision cooling device system for forcer.

NOTE H3b：Contain forcer, stator and precision cooling device system for stator.

NOTE S3 is the gap between Hall sensor and stator after motor assembly.

4.1.3 LMSC double thrust linear motor series

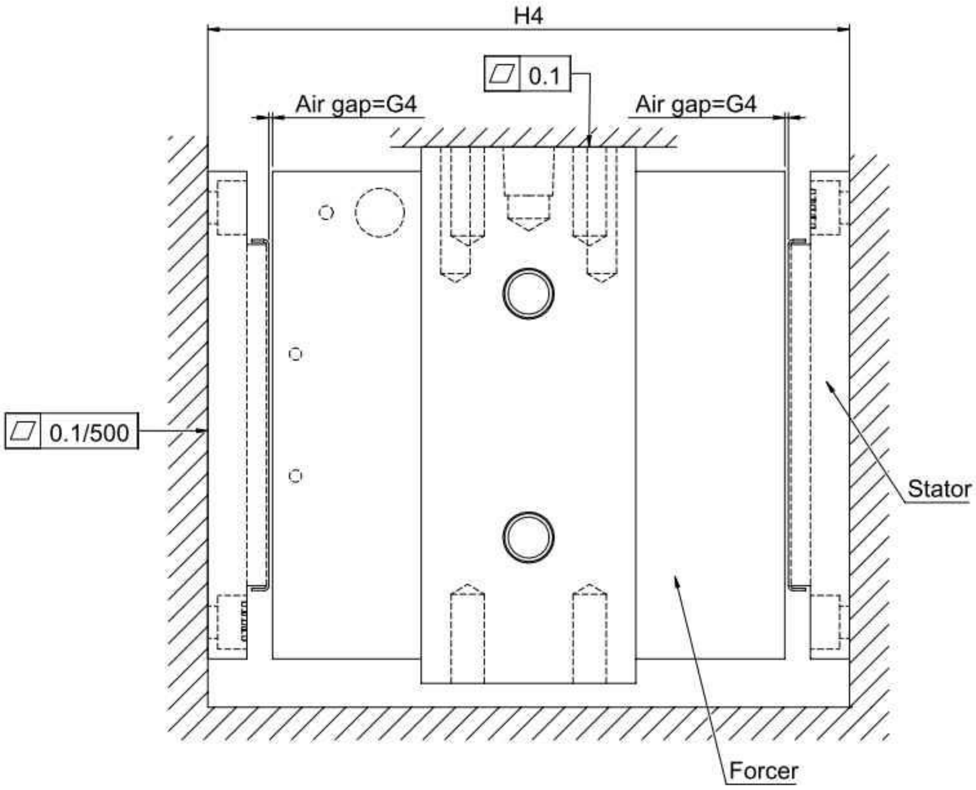


Figure 4.1-7 LMSC double thrust linear motor assembly

Table 4.1-4 LMSC double thrust linear motor assembly dimensions

Model	Dimensions (mm)	
	H4	G4
LMSC7	131.5	0.75 $_{+0.35/-0.2}$

4.1.4 LMSS iron core linear motor series

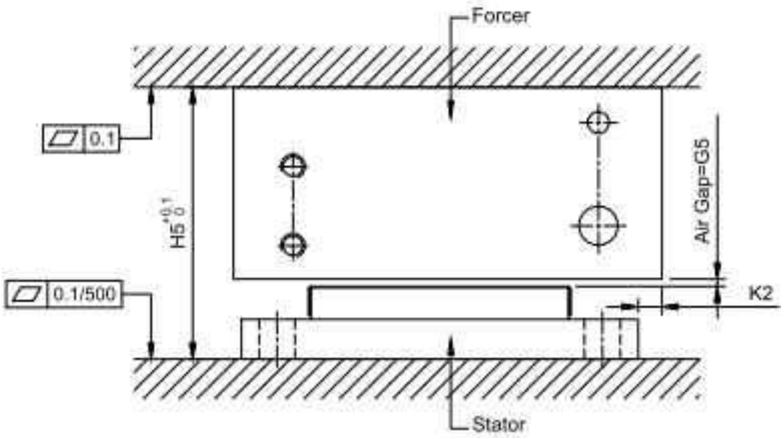


Figure 4.1-8 LMSS iron core linear motor assembly

Table 4.1-5 LMSS iron core linear motor assembly dimensions

Model	Dimensions (mm)		
	H5	K2	G5
LMSS11	34.3	3	0.9 +0.3/-0.35

4.2 Ironless linear motor (LMC) mechanical installation interface

For the installation surface (datum plane A) of a ironless linear motor fastened with a stator assembly, the recommended plane precision is 0.02mm/300mm; for the installation plane fastening with a forcer assembly, the recommended plane precision is 0.02mm/300mm, and it is parallel to the datum plane A, and the parallel precision is 0.02mm/300mm.

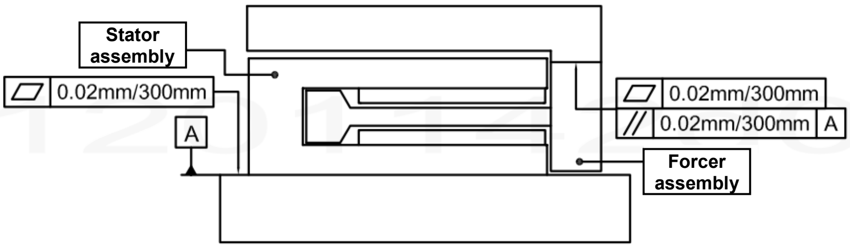


Figure4.2-1 Ironless linear motor installation interface assembly precision

When a ironless linear motor is installed with the forcer and stator assembly, please pay special attention to the dimensions (H & G1 & G2 & G3) between the forcer and stator, and such dimensions can affect the performance and reliability of the linear motor. (For values H & G1 & G2 & G3, please refer to Table 4.2-1)

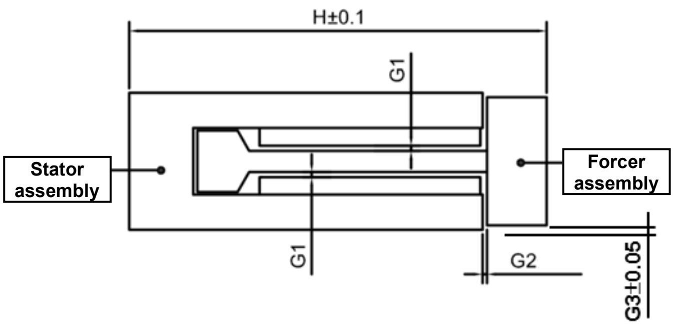


Figure4.2-2 Ironless linear motor installation dimension

Table 4.2-1 Ironless linear motor installation dimension chart

Model	Dimension (mm)			
	H	G1	G2	G3
LMCA	74.5	≧0.4	1	1
LMCB	94.5	≧0.4	1	1
LMCC	117.5	≧0.4	1	3
LMCD	105	≧0.4	1.2	1
LMCE	125	≧0.4	1.2	1
LMCF	172	≧0.4	1.2	2.3
LMC-EFC	68.5	≧0.4	1.3	0.35
LMC-EFE	93	≧0.4	1.3	0.35
LMC-EFF	122	≧0.4	1.4	0.5
LMC-HUB	53	≧0.4	0.5	0.65

4.3 Shaft linear motor (LMT) mechanical installation interface

For the fixation base installation surface (datum plane A) secured underneath the stator assembly, the recommended plane precision is 0.02mm/300mm. For the installation surface fastening the forcer assembly, the recommended plane precision is 0.02mm/300mm, and it is parallel to the datum plane A, and the parallel precision is 0.02mm/300mm.

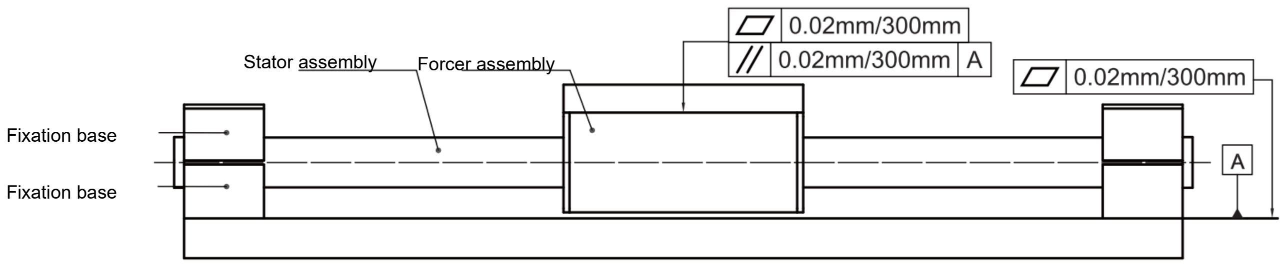


Figure4.3-1 Shaft linear motor installation interface geometric precision

The recommended design of stator fixation base is to use a V-shape sleeper.

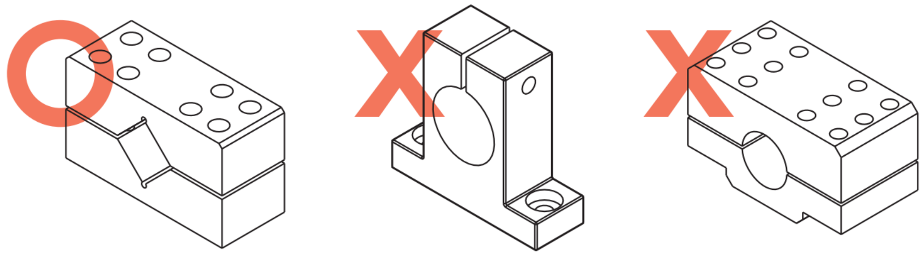


Figure4.3-2 Fixation base design

The fixation base length (L1) for securing the stator can be changed for different strokes.

Table 4.3-1 Securement length of fixation base

Model	LMT2D/LMT2T/LMT2Q		
Stroke S (mm)	50~350	400~800	850~1050
L1 (mm)	25	40	60
Model	LMT6D/LMT6T/LMT6Q		
Stroke S (mm)	100~350	400~800	850~1050
L1 (mm)	25	40	60
Model	LMTA2/LMTA3/LMTA4		
Stroke S (mm)	100~300	350~700	750~1550
L1 (mm)	25	40	60
Model	LMTB2/LMTB3/LMTB4		
Stroke S (mm)	100~700	750~1300	1350~1550
L1 (mm)	50	70	100
Model	LMTC2/LMTC3/LMTC4		
Stroke S (mm)	100~750	800~1500	1550~2000
L1 (mm)	50	70	100

Both H1 and H2 refer to the dimension of height from the datum plane A to the stator assembly center. It is recommended that after the installation of the stator assembly, the height difference shall not exceed 0.2mm; both W1 and W2 refer to the dimension of height from the datum plane B to the stator assembly center. It is recommended that after the installation of the stator assembly, the height difference shall not exceed 0.2mm; $|H1-H2| \leqq 0.2$mm; $|W1-W2| \leqq 0.2$mm. (as shown in Figure 4.3-3)

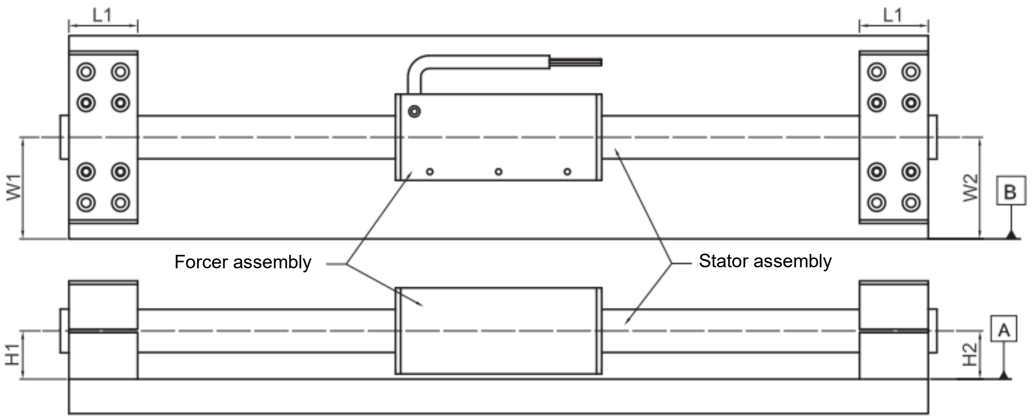


Figure 4.3-3 Stator assembly installation dimension

Datum C refers to the center of a stator assembly, and datum D refers to the reference axis of a forcer assembly. It is recommended that after the installation of the forcer and stator assemblies, the concentricity of datum C and datum D shall not be greater than 0.2mm. (as shown in Figure4.3-4)

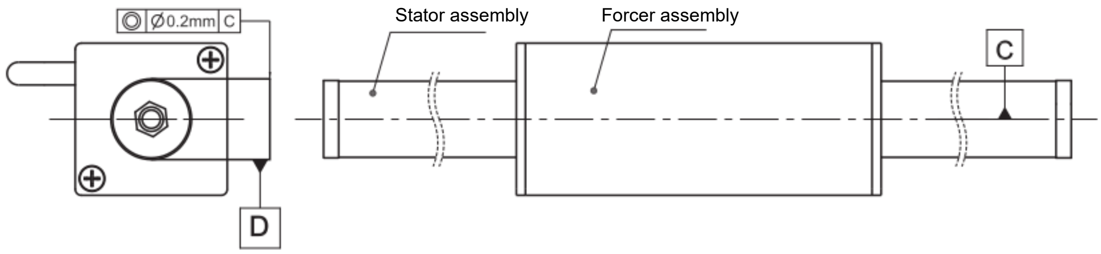


Figure4.3-4 Geometric tolerance of forcer and stator assembly installation height

During the installation of the forcer and stator assembly, please pay special attention to the dimension (G) between the forcer and stator, and such dimensions can affect the performance and reliability of the linear motor (as shown in Figure 4.3-5). (The values of G, ΦD1 are as shown in Table 4.3-2).

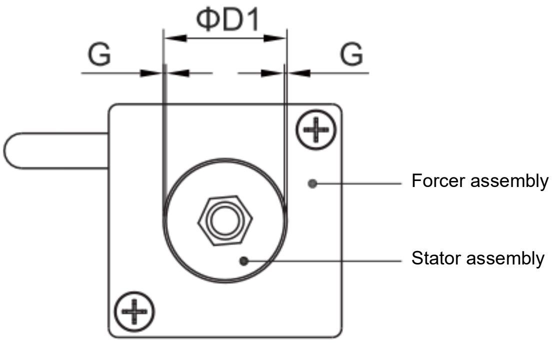


Figure 4.3-5 Forcer and stator installation dimensions precision

Table 4.3-2 Installation dimensions

Model	Dimensions (mm)	
	øD1	G
LMT2	13	0.25~0.50
LMT6	16	0.25~0.50
LMTA	21.5	0.375~0.75
LMTB	26.5	0.375~0.75
LMTC	37	0.50~1.00

The guideway is magnetic element which could easily generate attraction force with the stator. In order to avoid the stator be deformed by the attraction force and problems in installation, please keep the installation distance(c) as shown in Figure 4.3-5 and Table 4.3-3.

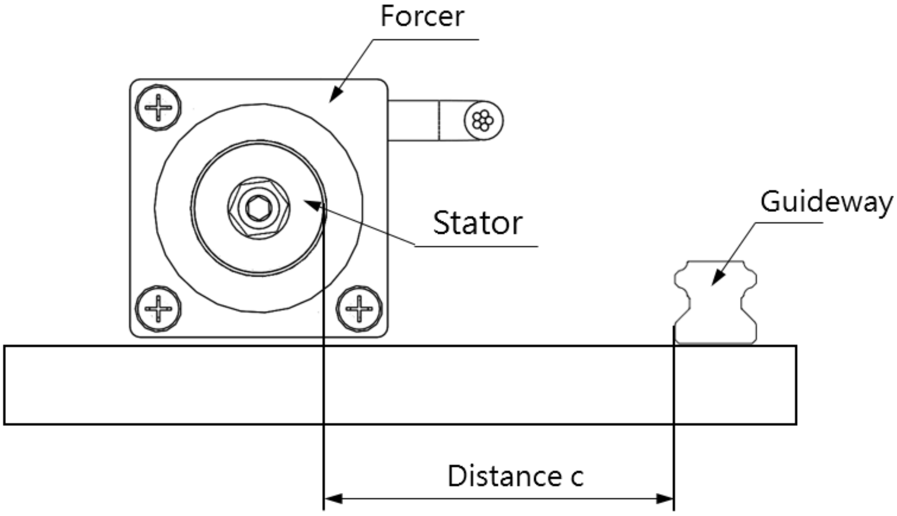


Figure 4.3-6 Installation distance while installing guideway

Table 4.3-3 Installation distance

Series	LMT2	LMT6	LMTA	LMTB	LMTC
c(mm)	≧30	≧30	≧40	≧50	≧80

The installation distance(d) as shown in Figure 4.3-7 and Table 4.3-4 should be kept as well while installing the magnetic scale, or it will easily cause interference in positioning if the magnetic field is too strong.

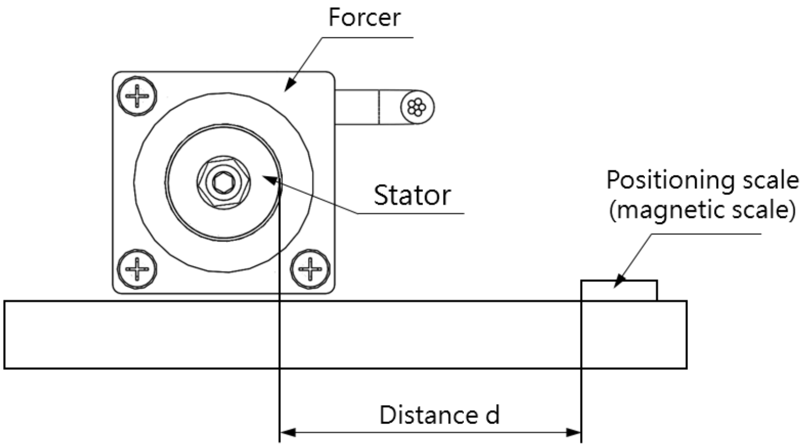


Figure 4.3-7 Installation distance while installing magnetic scale

Table 4.3-4 Installation distance

Series	LMT2	LMT6	LMTA	LMTB	LMTC
d(mm)	≧40	≧50	≧60	≧70	≧100

4.4 Forcer parallel design

Linear motors can be co-axially grouped with multiple sets of forcers in parallel for use. While multiple sets of forcers are installed in parallel, it is necessary to confirm that the motor models are identical to each other. In addition, assembly shall be performed according to the outlet direction and the parallel span (ΔX) design in order to ensure that the linear motor phases are the same before activation. The parallel span and installation outlet relationship of each series motor will be explained in a later chapter in more detail. For the motor parallel parameter calculation, please refer to Table 4.4-1.

Table 4.4-1 Motor parallel parameter calculation

	Single unit	2 units in parallel	3 units in parallel	4 units in parallel
Resistance (Ω)	A	A/2	A/3	A/4
Inductance (mH)	B	B/2	B/3	B/4
Force constant (N/Arms)	C	C	C	C
Back EMF constant (Vrms/(m/s))	D	D	D	D
Continuous current (Arms)	E	E*2	E*3	E*4
Peak current (Arms)	F	F*2	F*3	F*4
Continuous force (N)	G	G*2	G*3	G*4
Peak force (N)	H	H*2	H*3	H*4

4.4.1 Linear motor moving direction

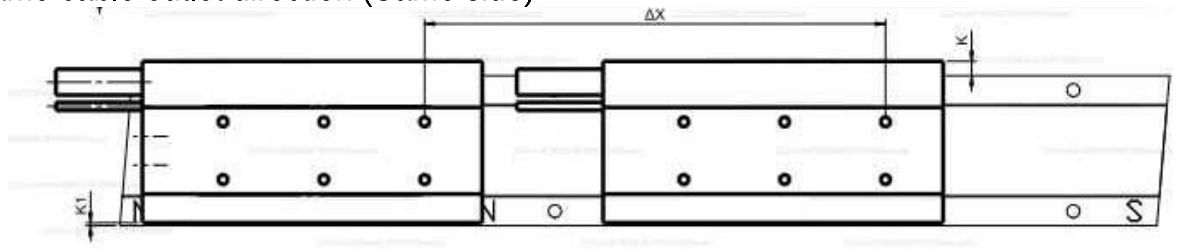
Definition of the positive direction of Linear motor as follow:

Input U/V/W in sequence, the initial moving direction is the positive direction.

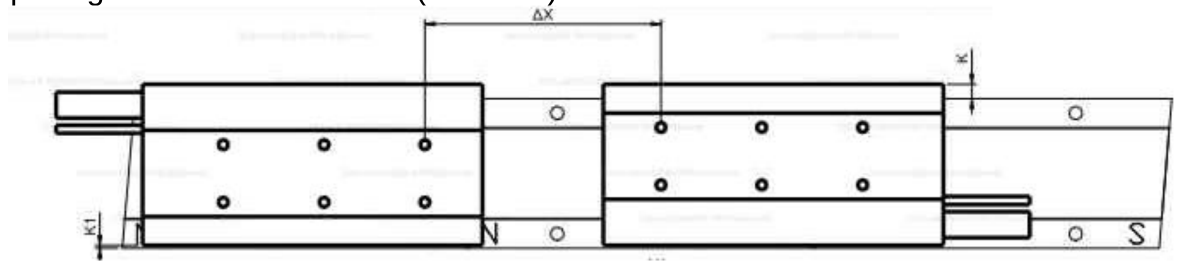
And please refer to 9.2 , moving direction of Linear motor.

4.4.2 LMSA linear motor series

Same cable outlet direction (Same side)



Opposing cable outlet direction (Outward)



Opposing cable outlet direction (Inward)

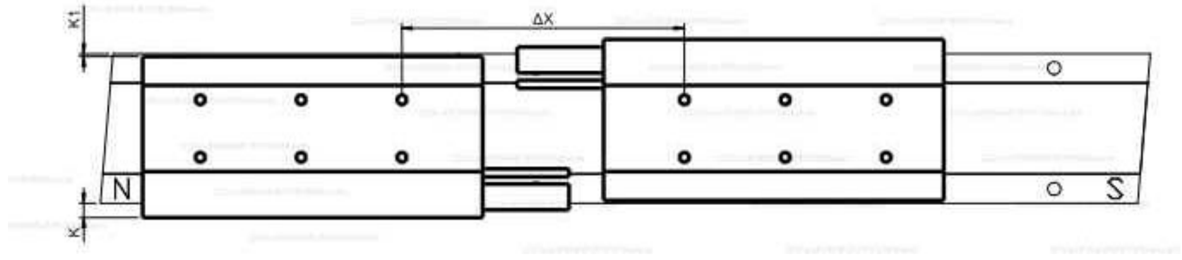


Figure 4.4-1 LMSA/LMSA-Z linear motor parallel connection illustration

Table 4.4-2 LMSA/LMSA- parallel wiring chart

LMSA/LMSA-Z	Same side			Outward			Inward		
Motor 1	U	V	W	U	V	W	U	V	W
Motor 2	U	V	W	W	V	U	W	V	U
ΔX (2P=30mm)	n*2P (n is an integer)			65+n*2P (n=0,1,2…etc)			65+n*2P (n=0,1,2…etc)		

4.4.3 LMFA/LMFP water-cooling linear motor series

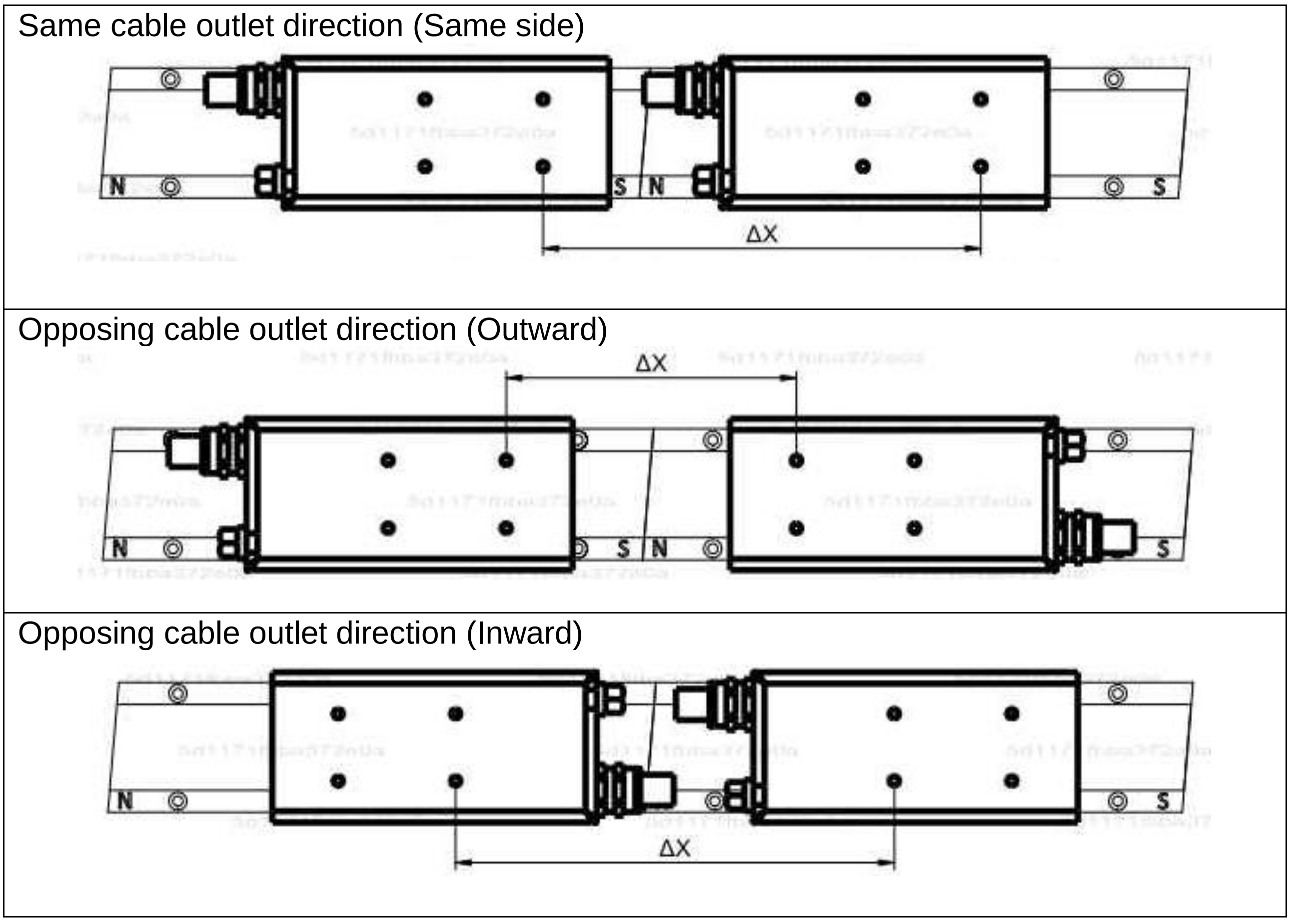


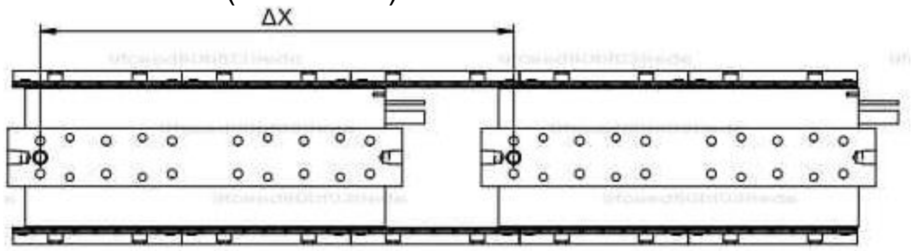
Figure 4.4-2 LMFA/LMFP linear motor parallel connection illustration

Table 4.4-3 LMFA/LMFP parallel wiring chart

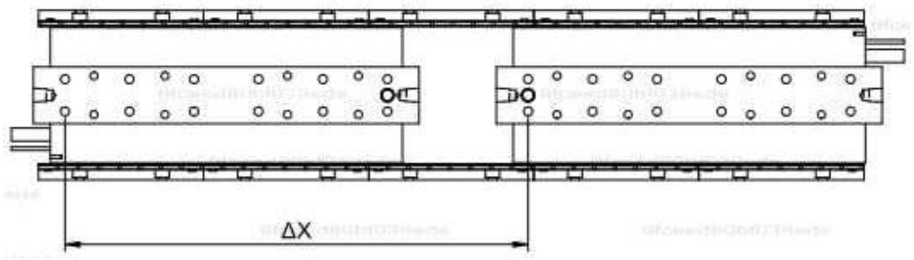
LMFA/LMFP	Same side			Outward			Inward			Model
Motor 1	U	V	W	U	V	W	U	V	W	
Motor 2	U	V	W	W	V	U	W	V	U	
ΔX (2P=30mm)	n*2P (n is an integer)			82.5+n*2P (n=0,1,2…etc)			322.5+n*2P (n=0,1,2…etc)			LMFA0~2 series LMFP24 series
ΔX (2P=46mm)	n*2P (n is an integer)			127+n*2P (n=0,1,2…etc)			402+n*2P (n=0,1,2…etc)			LMFA3~6 series LMFP3~6 series

4.4.4 LMSC magnetic brake linear motor series

Same cable outlet direction (Same side)



Opposing cable outlet direction (Outward)



Opposing cable outlet direction (Inward)

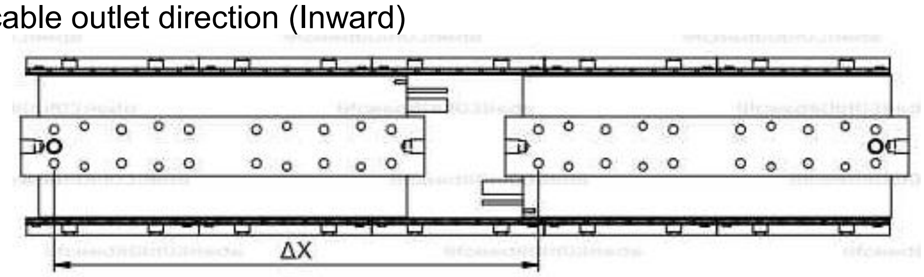


Figure 4.4-3 LMSC linear motor parallel connection illustration

Table 4.4-4 LMSC parallel wiring chart

LMSC	Same side			Outward			Inward		
Motor 1	U	V	W	U	V	W	U	V	W
Motor 2	U	V	W	W	V	U	W	V	U
ΔX (2P=32mm)	320+n*2P (n=1,2,3…etc)								

4.4.5 LMSS linear motor series

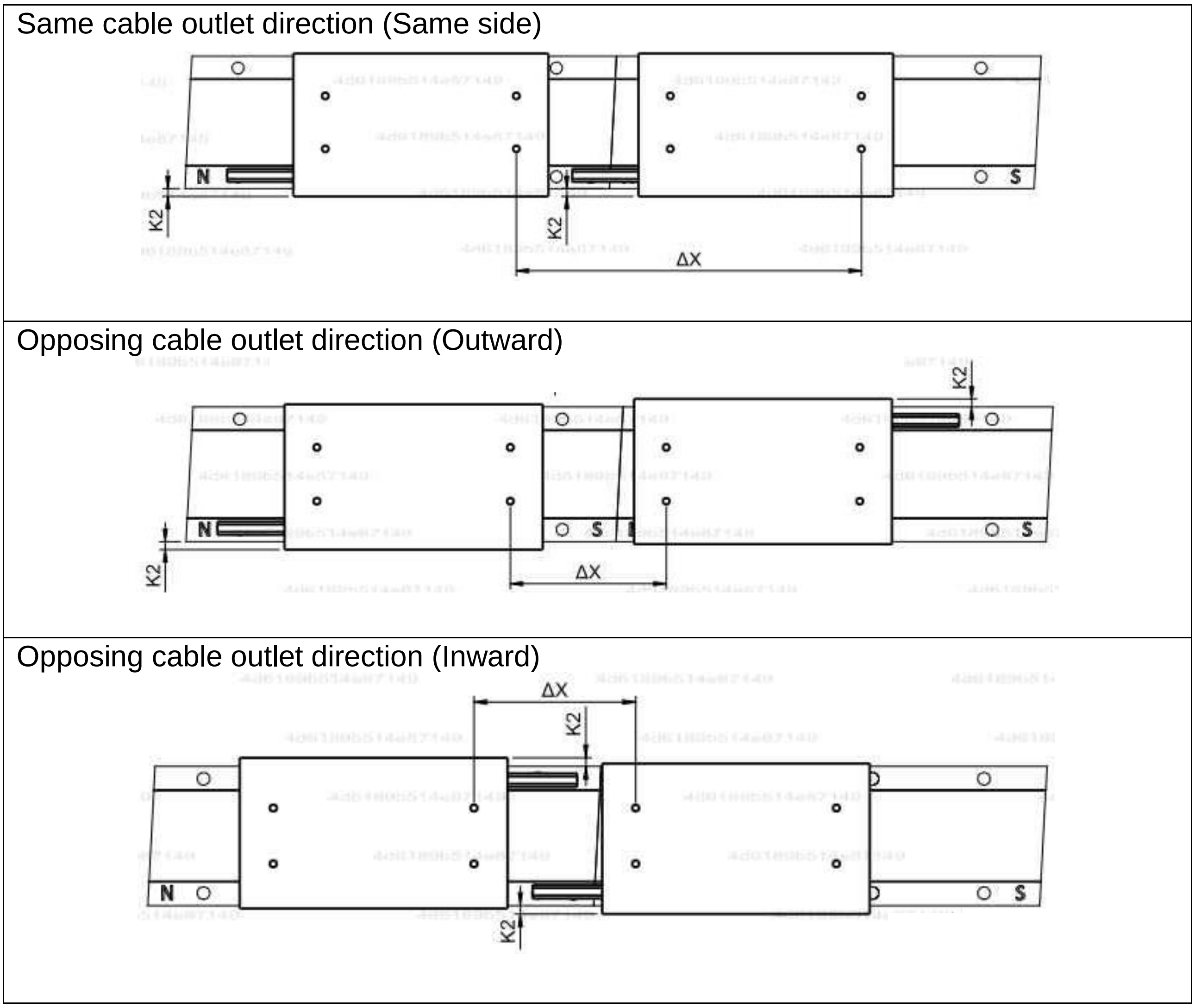


Figure 4.4-4 LMSS linear motor parallel connection illustration

Table 4.4-5 LMSS parallel wiring chart

LMSS	Same side			Outward			Inward		
Motor 1	U	V	W	U	V	W	U	V	W
Motor 2	U	V	W	W	V	U	W	V	U
ΔX (2P=20mm)	n*2P (n is an integer)			35+n*2P (n=0,1,2…etc)			81+n*2P (n=0,1,2…etc)		

4.4.6 LMC ironless linear motor series

LMC A/B/C/D/E/F series

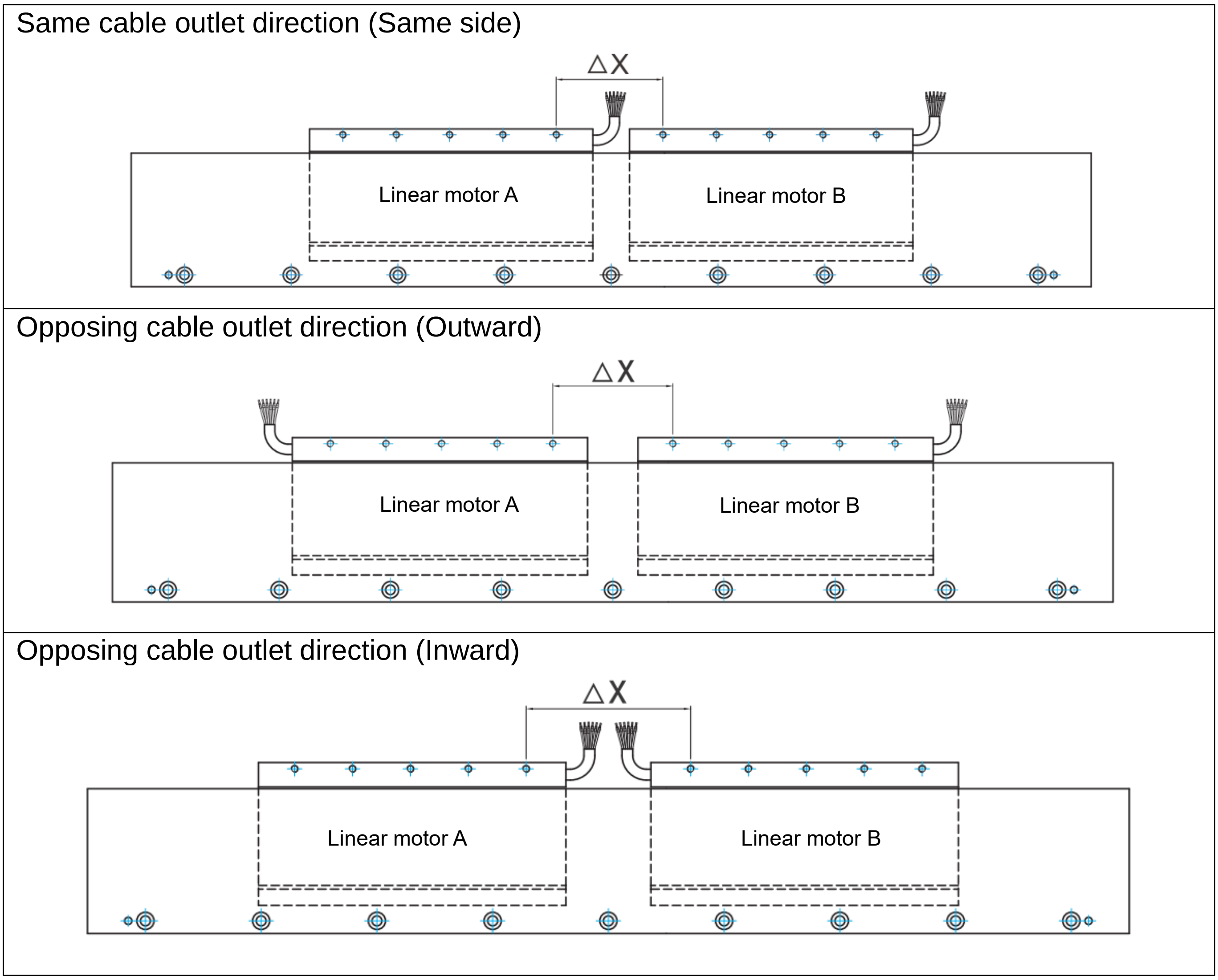


Figure4.4-5 LMC A/B/C/D/E/F linear motor parallel connection illustration

Table 4.4-6 LMCA/B/C parallel wiring chart

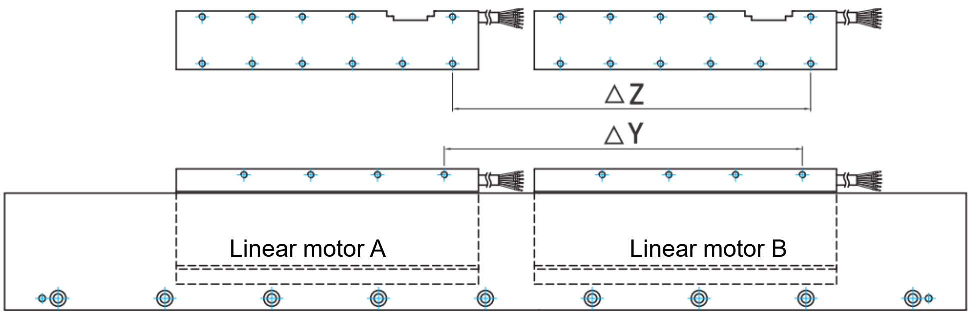
LMCA/B/C	Same side			Outward			Inward		
Linear motor A	U	V	W	U	V	W	U	V	W
Linear motor B	U	V	W	W	V	U	W	V	U
ΔX (2P=32mm)	32+n*2P (n=1,2…)			18+n*2P (n=1,2…)			46+n*2P (n=1,2…)		

Table 4.4-7 LMCD/E/F parallel wiring chart

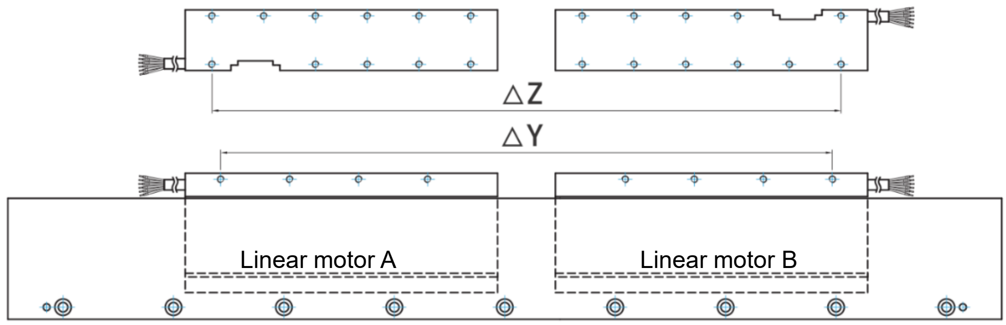
LMCD/E/F	Same side			Outward			Inward		
Linear motor A	U	V	W	U	V	W	U	V	W
Linear motor B	U	V	W	U	W	V	V	U	W
ΔX (2P=60mm)	60+n*2P (n=1,2…)			50+n*2P (n=0,1,2…)			50+n*2P (n=0,1,2…)		

LMC-EF series

Same cable outlet direction (Same side)



Opposing cable outlet direction (Outward)



Opposing cable outlet direction (Inward)

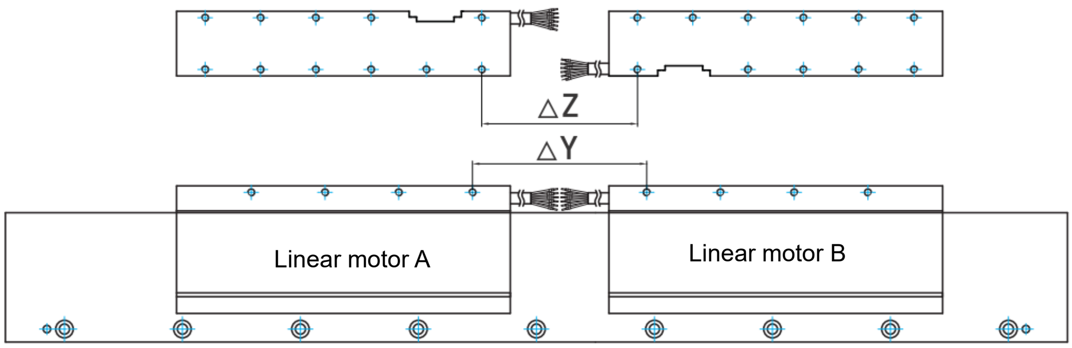


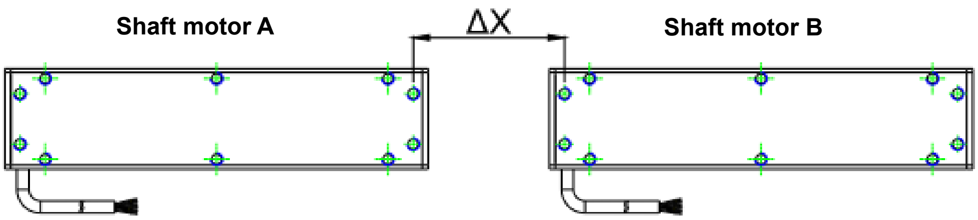
Figure 4.4-6 LMC-EF linear motor parallel connection illustration

Table 4.4-8 LMC-EF parallel wiring chart

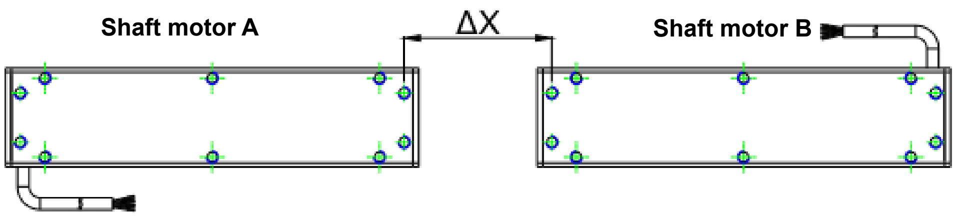
LMC-EFC	Same side			Outward			Inward		
Linear motor A	U	V	W	U	V	W	U	V	W
Linear motor B	U	V	W	U	W	V	V	U	W
ΔY (2P=60mm)	n*2P			90+n*2P			10+n*2P		
ΔZ	n*2P			100+n*2P			n*2P		
n	LMC-EFC1：n=2,3,4… LMC-EFC2：n=3,4,5… LMC-EFC3：n=4,5,6… LMC-EFC4：n=5,6,7…			LMC-EFC1：n=0,1,2… LMC-EFC2：n=2,3,4… LMC-EFC3：n=4,5,6… LMC-EFC4：n=6,7,8…			n=2,3,4…		
LMC-EFE	Same side			Outward			Inward		
Linear motor A	U	V	W	U	V	W	U	V	W
Linear motor B	U	V	W	U	W	V	V	U	W
ΔY (2P=60mm)	n*2P			90+n*2P			10+n*2P		
ΔZ	n*2P			99+n*2P			1+n*2P		
n	LMC-EFE1：n=2,3,4… LMC-EFE2：n=3,4,5… LMC-EFE3：n=4,5,6… LMC-EFE4：n=5,6,7… LMC-EFE5：n=6,7,8… LMC-EFE6：n=7,8,9…			LMC-EFE1：n=0,1,2… LMC-EFE2：n=2,3,4… LMC-EFE3：n=4,5,6… LMC-EFE4：n=6,7,8… LMC-EFE5：n=8,9,10… LMC-EFE6：n=10,11,12…			n=2,3,4…		

4.4.7 LMT Shaft linear motor series

Same cable outlet direction (Same side)



Opposing cable outlet direction (Outward)



Opposing cable outlet direction (Inward)

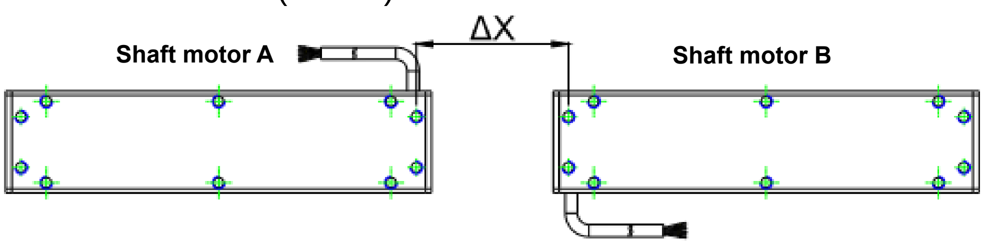


Figure 4.4-7 LMT linear motor parallel connection illustration

Table 4.4-9 LMT same cable outlet direction parallel wiring chart

LMT 2D/2Q	Same side			LMT 2T	Same side		
Linear motor A	U	V	W	Linear motor A	U	V	W
Linear motor B	U	V	W	Linear motor B	U	V	W
ΔX (2P=48mm)	n*2P-8.2 (n=1,2,3…)			ΔX (P=24mm)	(2n-1)*P-8.2 (n=1,2,3…)		
LMT 6D/6Q	Same side			LMT 6T	Same side		
Linear motor A	U	V	W	Linear motor A	U	V	W
Linear motor B	U	V	W	Linear motor B	U	V	W
ΔX (2P=60mm)	n*2P-10.5 (n=1,2,3…)			ΔX (P=30mm)	(2n-1)*P-10.5 (n=1,2,3…)		
LMT A2/A4	Same side			LMT A3	Same side		
Linear motor A	U	V	W	Linear motor A	U	V	W
Linear motor B	U	V	W	Linear motor B	U	V	W
ΔX (2P=72mm)	n*2P-12 (n=1,2,3…)			ΔX (P=36mm)	(2n-1)*P-12 (n=1,2,3…)		
LMT B2/B4	Same side			LMT B3	Same side		
Linear motor A	U	V	W	Linear motor A	U	V	W
Linear motor B	U	V	W	Linear motor B	U	V	W
ΔX (2P=90mm)	n*2P-15 (n=1,2,3…)			ΔX (P=45mm)	(2n-1)*P-15 (n=1,2,3…)		
LMT C2/C4/C6	Same side			LMT C3/C5	Same side		
Linear motor A	U	V	W	Linear motor A	U	V	W
Linear motor B	U	V	W	Linear motor B	U	V	W
ΔX (2P=120mm)	n*2P-20 (n=1,2,3…)			ΔX (P=60mm)	(2n-1)*P-20 (n=1,2,3…)		

Table 4.4-10 LMT different cable outlet directions parallel wiring chart

LMT 2 series	Outward			Inward		
Linear motor A	U	V	W	V	U	W
Linear motor B	V	U	W	U	V	W
ΔX (2P=48mm)	n*2P-8.2 (n=1,2,3…)					
LMT 6 series	Outward			Inward		
Linear motor A	U	V	W	V	U	W
Linear motor B	V	U	W	U	V	W
ΔX (2P=60mm)	n*2P-10.5 (n=1,2,3…)					
LMT A series	Outward			Inward		
Linear motor A	U	V	W	V	U	W
Linear motor B	V	U	W	U	V	W
ΔX (2P=72mm)	n*2P-12 (n=1,2,3…)					
LMT B series	Outward			Inward		
Linear motor A	U	V	W	V	U	W
Linear motor B	V	U	W	U	V	W
ΔX (2P=90mm)	n*2P-15 (n=1,2,3…)					
LMT C series	Outward			Inward		
Linear motor A	U	V	W	V	U	W
Linear motor B	V	U	W	U	V	W
ΔX (2P=120mm)	n*2P-20 (n=1,2,3…)					

4.5 LMFA/LMFP Water-cooling motor cooling tube design

When a multiple number of linear motors are used, the cooling tubes of the motor must be installed in the parallel method, as shown in Figure 4.5-1 (the inlet at the left side of the motor is connected to the inlet at the right side of the motor, and the outlets are also connected in the same way). When precision water-cooling is used, the channel is as shown in Figure4.5-2. For multiple precision water-cooling channels, please refer to Figure4.5-3.

Recommendation: Separate the channels of the forcer precision water-cooling and the stator precision water-cooling for operation can achieve greater effect.

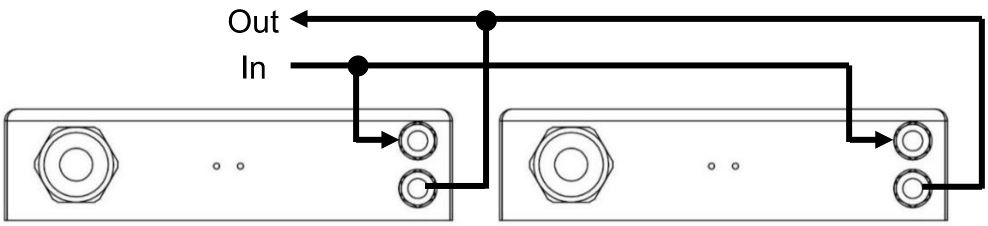


Figure 4.5-1 Motor cooling tube installation illustration

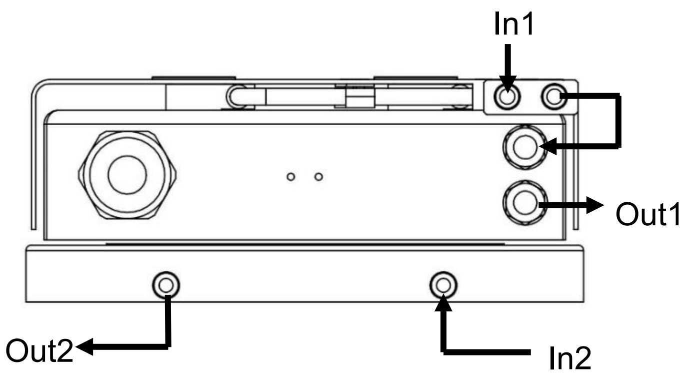


Figure4.5-2 Precision water-cooling channel illustration

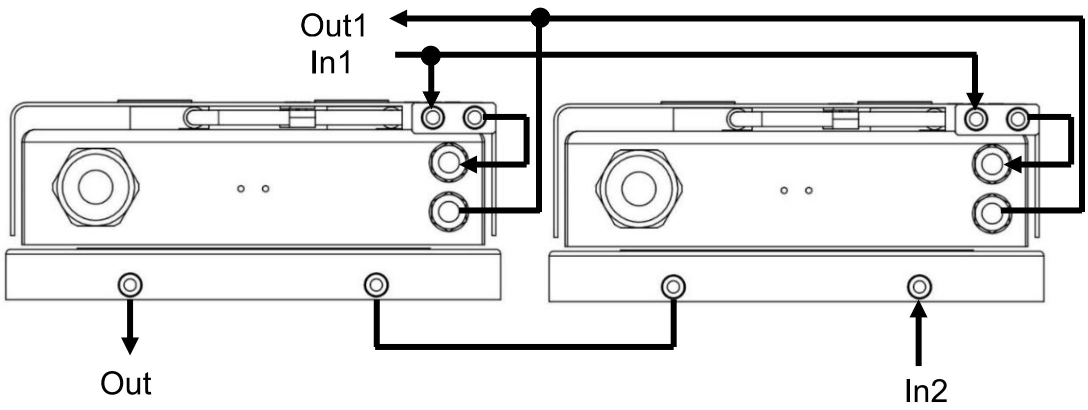


Figure4.5-3 Multiple precision water-cooling channels illustration

4.6 LMFA/LMFP water-cooling motor with LMFC precision water-cooling channel design

During the use of the water-cooling linear motor LMFA/LMFP along with the precision water-cooling series LMFC, the motor characteristic indicated on the HIWIN water-cooling motor drawings and specification refers to the water-cooling condition, and the coolant temperature is 20℃. The water-cooling motor can also use oil cooling, and at this time, the motor performance may be adjusted appropriately according to the characteristic of the coolant.

The cooling condition indicated in the motor specification refers to the continuous running condition when the motor stator is under the criteria of Continuous force, thereby ensuring the coil temperature is controlled under the minimum criteria of below 120℃. The performance of LMFC precision water-cooling is defined to be that the precision water-cooling surface temperature shall not be higher than the cooling machine outlet temperature setting by more than 4℃. LMFC stator precision water-cooling includes the following two types, and the LMFC3~6 series adopts the standard type water channel design, as shown in Figure4.6-1; LMFC3~4 series adopts the return flow type water channel design, as shown in Figure4.6-2.

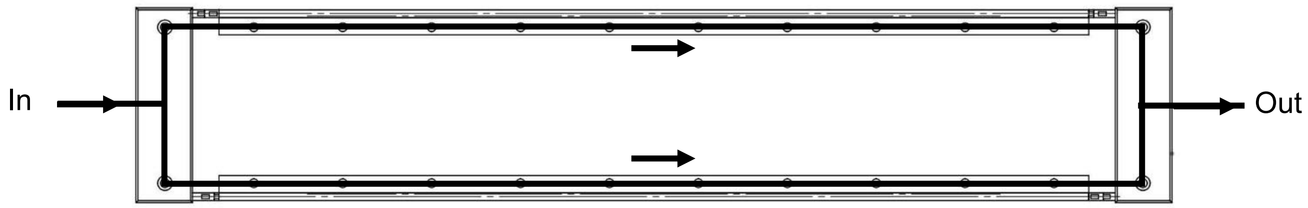


Figure4.6-1 Standard type water channel illustration

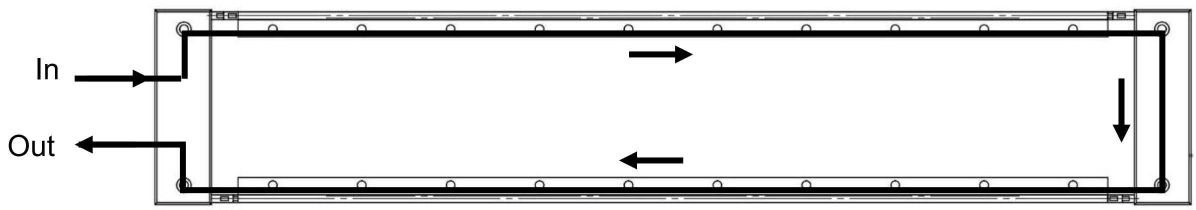


Figure4.6-2 Return flow type water-cooling channel illustration

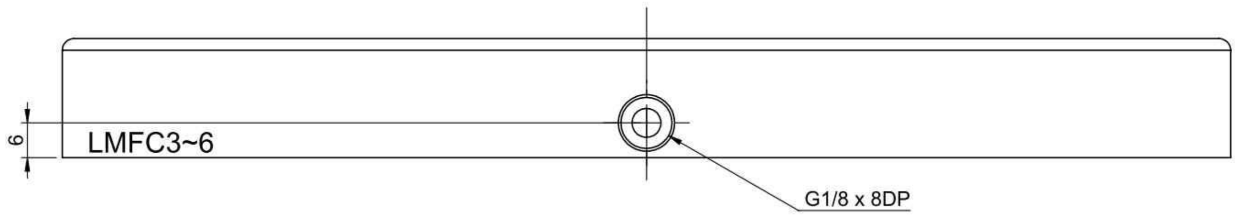


Figure4.6-3 Standard type installation interface

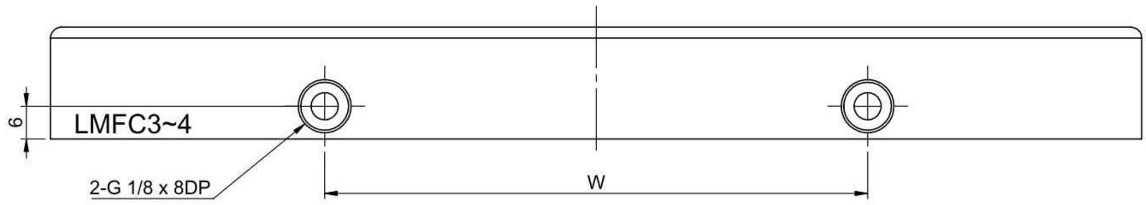


Figure4.6-4 Return flow type installation interface

Table 4.6-1 Return flow type Installation dimension chart

Model	Dimensions (mm)
	W
LMFC3□	50
LMFC4□	100

LMFC Precision water-cooling linear motor assembly illustration is as shown in the drawing below

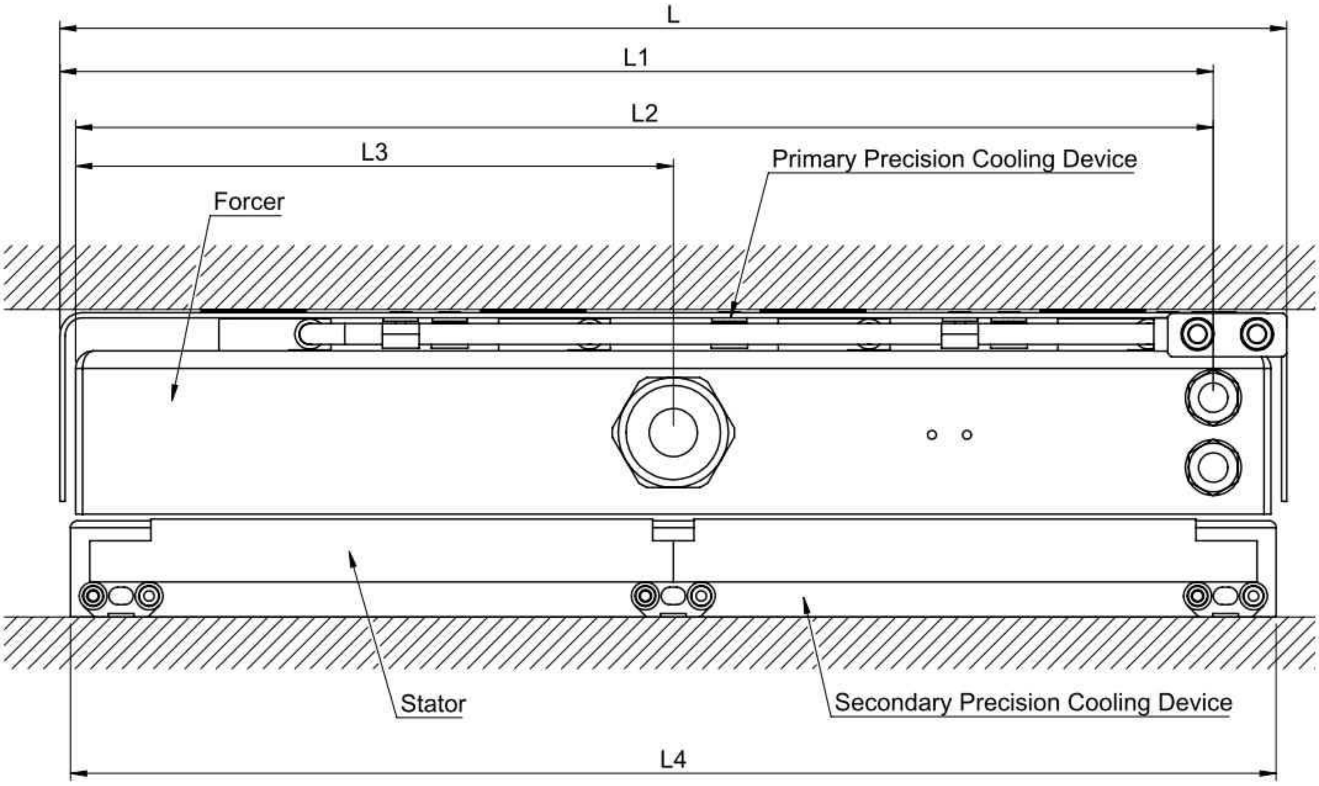


Figure4.6-5 LMFA precision water-cooling linear motor assembly illustration

Table 4.6-2 LMFA precision water-cooling installation dimension

Model	Dimensions (mm)				
	L	L1	L2	L3	L4
LMFC0□					
LMFC1□					
LMFC2□					
LMFC3□	150	131	126.5	30	155
LMFC4□	197	178	173.5	30	201
LMFC5□	257	236	231.5	124	251
LMFC6□	351	330	325.5	171	345

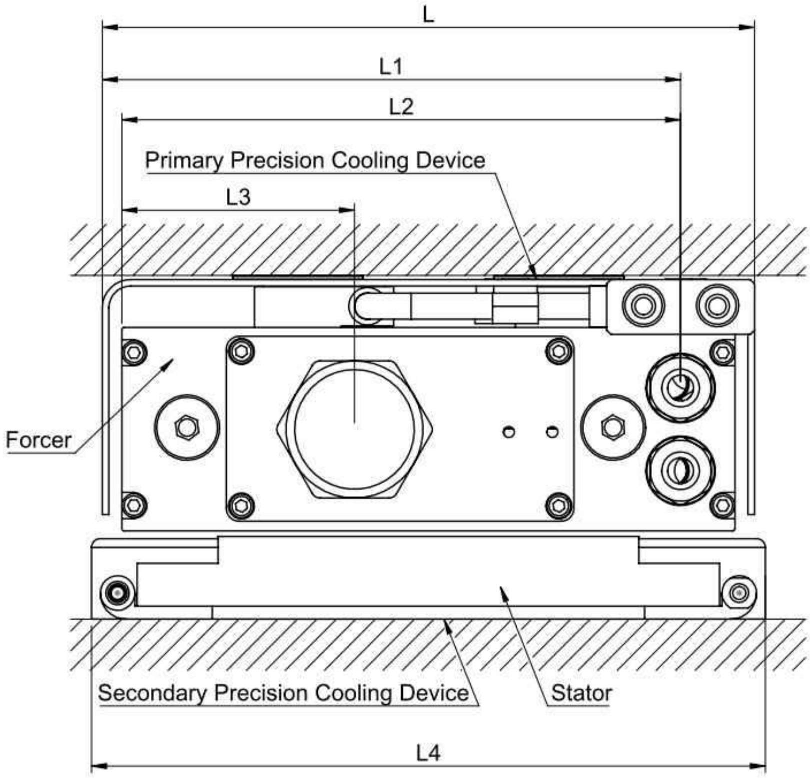


Figure 4.6-6 LMFP precision water-cooling linear motor assembly illustration

Table 4.6-3 LMFP precision water-cooling installation dimension

Model	Dimensions (mm)				
	L	L1	L2	L3	L4
LMFC0□					
LMFC1□					
LMFC2□					
LMFC3□	150	133	128.5	53.5	155
LMFC4□	197	180	175.5	53.5	201
LMFC5□	257	240	235.5	53.5	251
LMFC6□	351	334	329.5	53.5	345

4.7 Material used in water-cooling channel

Table 4.7-1 Water-cooling channel material chart

Item	Material
LMFA water-cooling linear motor	Cu (SF-Cu), SUS303 (1.4305), Viton
LMFC forcer precision water-cooling	A6061 (AlMgSi0.5), SUS304 (1.4301), Viton
LMFC stator precision water-cooling	A6061 (AlMgSi0.5), SUS303 (1.4305), Viton

4.8 Coolant of water-cooling linear motor

ATTENTION!

Risk of working temperature.
Beware the operating environment of the cooling system to avoid damage.
- Please do not use the cooling system in frosty or icy environment
- Please do not use untreated water, or it might cause serious damage or break down

Customer could decide which cooling system and coolant to use with below requirements.

- It is recommended to use anti-corrosion water as the coolant.
- The cooling medium must be cleaned or filtered in advance to prevent blockage of the cooling circuit.
- The maximum allowable size of particles in the cooling medium is 100μm.
- Coolant must be compatible with O-ring material to avoid pollution.
- Recommended additive including.
  - Ethylene glycol (thermosensitivity)
  - Ethylene glycol with 20%-30% softened water
  - Water with 3% Panolin
  - Water with 10%-20% Tyfocor
  - Water with 30% Clysantin
  - Oil with 7 cst viscosity

Water which is used as basis for the coolant must comply as a minimum with the following requirements.

- Chloride concentration: c < 100 mg/l
- Sulfate concentration: c < 100 mg/l
- $6.5 \leqq$ pH value $\leqq 9.5$

Contact the anti-corrosion agent manufacturer relating to additional requirements!

5. Motor assembly

5.1 Iron core linear motor installation

Stator unit warning label

Caution! Strong magnetic field!
Keep away from anyone with a heart pacemaker or metal implants!
Be careful with the risk of hand injury when dealing with it.
Do not handle it with ferrous tools.
Credit cards, ATM cards, magnetic data carriers, wristwatches, etc. may be damaged when brought too near.

HIWIN
HIWIN MIKROSYSTEM CORP.

5.1.1 Precautions for handling stator

⚠ WARNING!

Risk of Stator access.
To avoid damage to products and harm to workers, take the stator in the correct way.
- The magnet warning label shall be attached at visible areas in order to prevent personnel injury.
- Please handle the stator with proper method in order to prevent personnel injury or stator damage.
- Please correctly take the stator to prevent personnel from injury or the stator from being damaged. (refer to Figure 5.1-1).
- No matter what method is used, do not directly take the stator by handling the edge of the cover (refer to Figure 5.1-2) Otherwise, personnel may get injured and the stator may be damaged.

⚠ WARNING!

Risk of crushing from strong attraction forces.
The permanent magnets of the stators cause strong attraction and repulsion forces when the stator segments are connected in series.
- Do not remove stators from their packaging until directly before their installation.
- Never unpack several stators at the same time.
- Never place stators next to each other unsecured.
- Immediately mount unpacked stators.
- If the installation component with cable, must also pay attention to the risk of pinching.

⚠ WARNING!

Risk of injury and material damage.
Incorrect alignment of the stator segments can lead to malfunction and/or uncontrolled movement of the motor.
- Arrange the stator segments in the correct order. (refer to Figure 5.1-3)

⚠ WARNING!

Risk of death as a result of permanent magnet field.

Even when the motor is switched off, the permanent can put people with active medical implants at risk, who come close to the motors.

- Please be at least 50 mm away from the permanent magnets.
- People with heart rhythm devices or metal implants, maintain a minimum distance of 500 mm from the permanent magnets (trigger threshold for static magnetic fields of 0.5 mT as per directive 2013/35/EU).

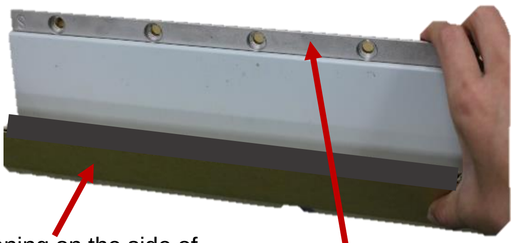
⚠ WARNING!

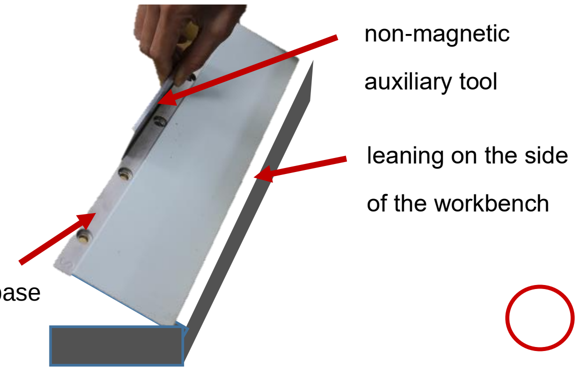
Risk of damage as a result of permanent magnet field.

When working within a distance of 100 mm of components with permanent magnets, the magnetic field produces a strong magnetic attraction to magnetizable material.

- Do not underestimate the strength of magnetic attraction.
- In the induction zone, please do not carry the magnetizable material.
- Please use the tools that non-magnetized material.
- Please avoid the movement of the permanent magnet assembly relative to the conductive material, and the conductive material relative to the permanent magnet assembly.
- Only open the package of the motor assembly when it needs to be installed.
- When open the package, install components containing permanent magnets immediately.
- The installed Linear motor that needs to prevent accidental operation.

■ Correct

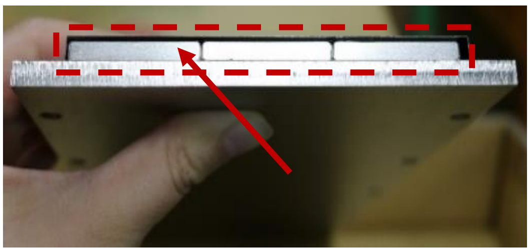


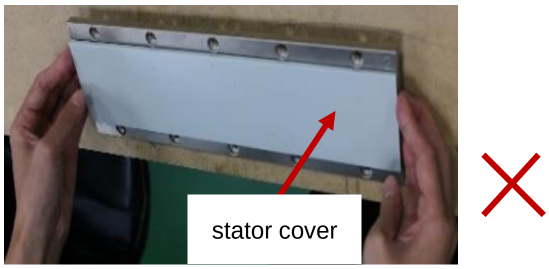


Lean the stator on one side of the workbench. Hold the stator by handling its base.	Lean the stator on one side with the non-magnetic auxiliary tool. Hold the stator by handling its base.

Figure 5.1-1 Correct method of handling the stator

■ Incorrect

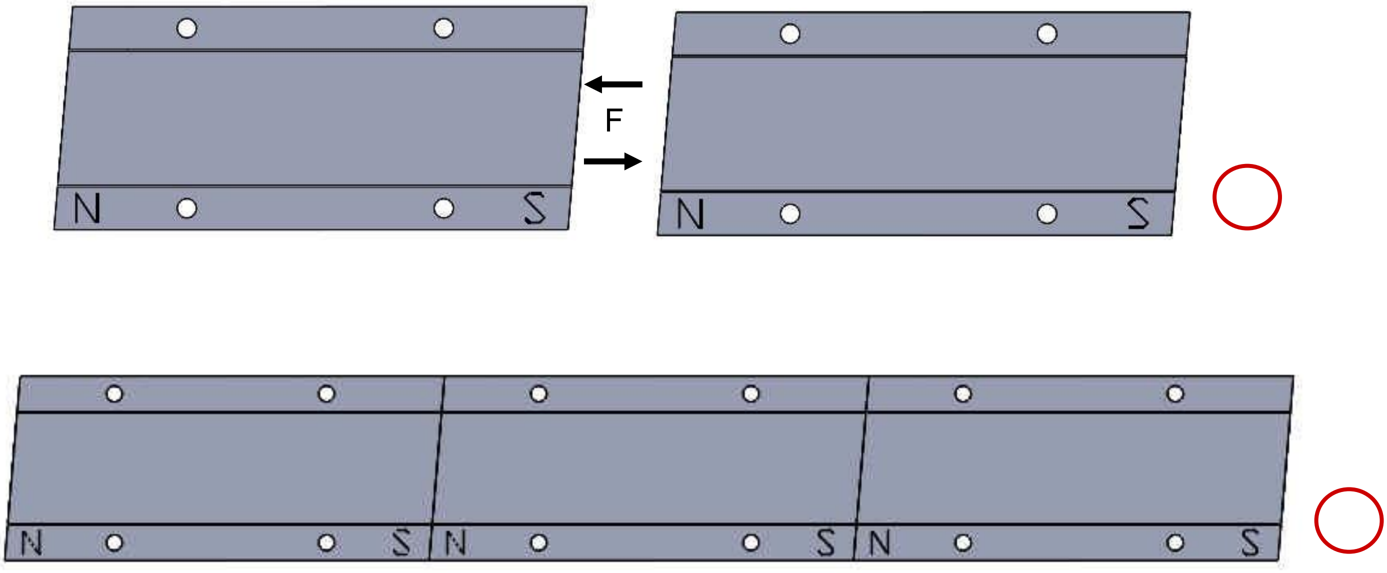




Do not hold the stator by handling the edge of the cover.	To prevent personnel from injury or the stator from being damaged, taking the stator by contacting the edge of the cover is strictly prohibited.

Figure 5.1-2 Incorrect method of handling the stator

- Correct assembly of stator



- Incorrect assembly of stator

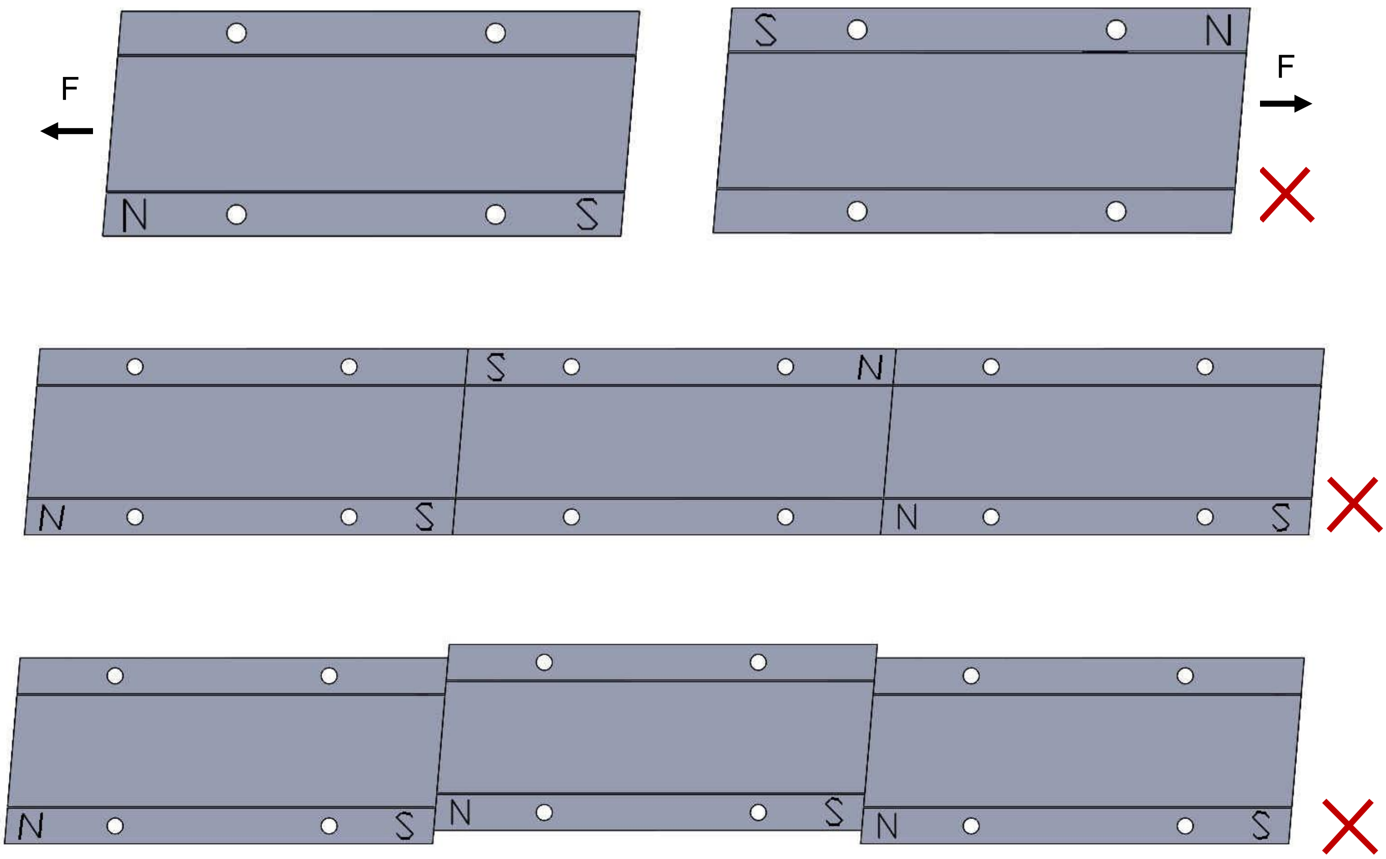


Figure 5.1-3 Correct and incorrect assembly of stator

5.1.2 Precautions for installation of forcer and stator

⚠ DANGER!

Danger from strong magnet!

There is strong magnetic attraction between forcer and stator. To avoid harm to workers, conform to the regulations.

- There is a powerful attraction force (several hundred kilogram of force) between the forcer and stator of LMSA／LMFA. Installation personnel are requested to follow the Manual to perform the installation in order to prevent clamping injury by the forcer and stator.

⚠WARNING!

Risk of Linear Motor assembly.

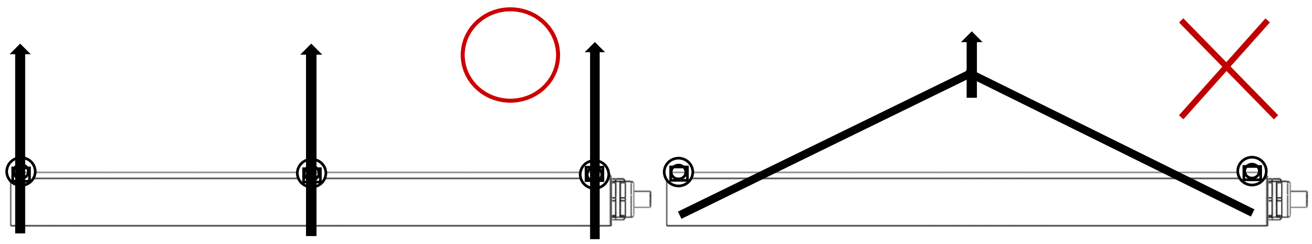
To avoid harm to workers, install the forcer and stator according to the regulations.

- When a multiple set of forcers are installed in parallel, please be aware of the span specification and motor phase in order to ensure the effective thrust force.
- During the installation of the forcer, please be aware of the air gap between the forcer and the stator. If it is not installed properly, it may increase the cogging force or reduce the motor thrust force.
- Before installation of the forcer, it is normal as a gap exists when the forcer is placed on the platform, as shown in Figure 5.1-7. To install the forcer assembly, fasten the screws from the center portion toward the two left and right ends sequentially, as shown in Figure5.1-8. After the fastening is complete, there is no air gap between the forcer and the forcer base, as shown in Figure 5.1-9.
- Please be aware of the strong magnetic attraction force between the two stators. It is prohibited to place hands between the two stators (as shown in Figure 5.1-12) in order to prevent personnel injury (magnetic objects and watches etc shall also be kept away).
- During the installation of a multiple sets of stators, the stator length may have accumulated tolerance such that hole position deviation may occur. Such occurrences are normal. Consequently, during the installation, a spacer of 0.1~0.2 mm can be placed between two stators to assist the adjustment of the screw positioning (as shown in Figure 5.1-13), and once the positioning is complete, then perform fastening. After fastening is complete, then remove the spacer.

ATTENTION!

- For the screw torque strength for fastening the forcer and stator assembly, please refer to Section 9.1.2.
- The maximum fastening depth of screws selected for the stator depends on the threaded holes of the customer's platform. For the minimum fastening depth, please refer to Section 9.1.2.
- For the maximum fastening depth and the minimum fastening depth of screws selected for the forcer, please refer to Section 9.1.2.

To transport a large forcer (such as LMFA), it is necessary to use a lifting tool and ensure that it is completely opposite from each other at both ends in order to perform the transportation. If the forcer weight is >20kg, please use more than three ropes for lifting in order to prevent any danger.



Step to assemble：

- First stator installation

  First, install one set of the stator. During installation, please be aware of the level of parallelism of the sliding track and the stator, followed by using screws to ① install ② the stator on the platform ③. (refer to Figure5.1-4)

- Forcer base and forcer installation.

  Use screws ④ to install the ⑤ forcer base onto the sliding block ⑥.(refer to Figure5.1-5)

  Use screws to install ⑧ the forcer ⑦ onto the forcer base. The installation method shall be performed by fastening the screws from the center portion toward the two left and right ends sequentially. (refer to Figure5.1-6)

- Stator installation.

  Move the forcer base ⑨ on top of the platform to facilitate the installation of other stator. (refer to Figure5.1-10)

  Use screws to install ⑪ the stator ⑩ onto the platform, and slide to move the forcer base to ensure that there is no interference. (refer to Figure5.1-11)

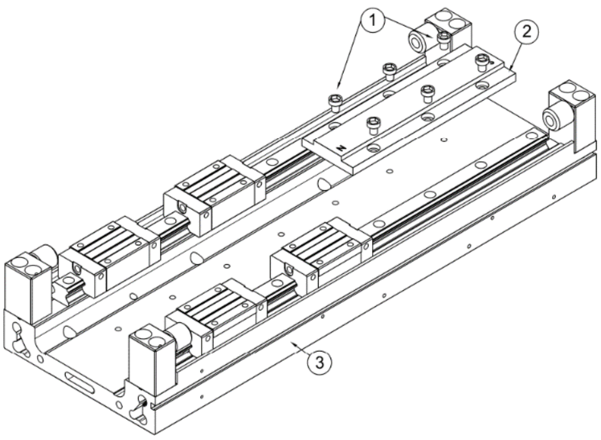


Figure5.1-4 First stator installation

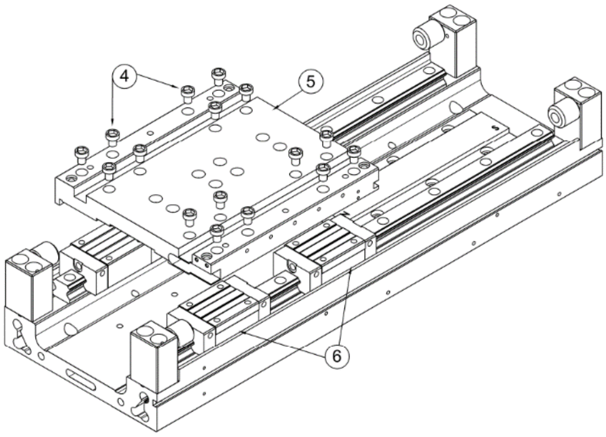


Figure5.1-5 Forcer base installation

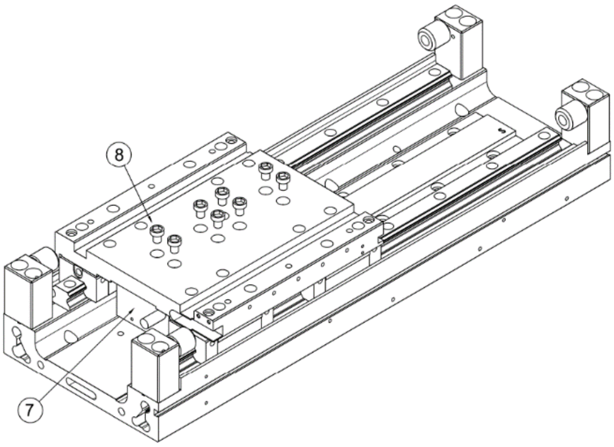
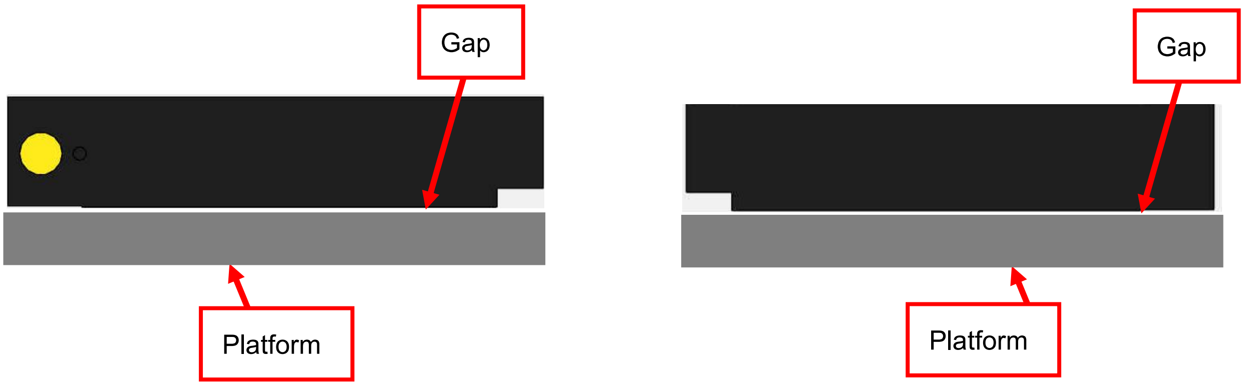


Figure5.1-6 Forcer installation



The front of the motor

The rear of the motor

Figure 5.1-7 Installation gap confirmation

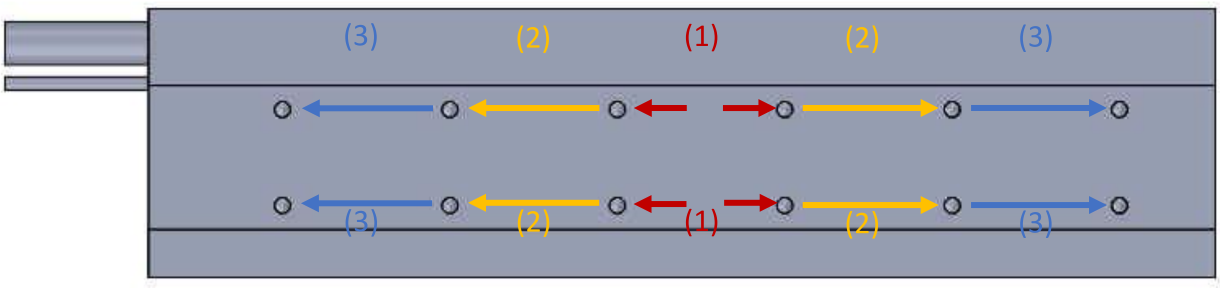


Figure5.1-8 Forcer installation sequence illustration

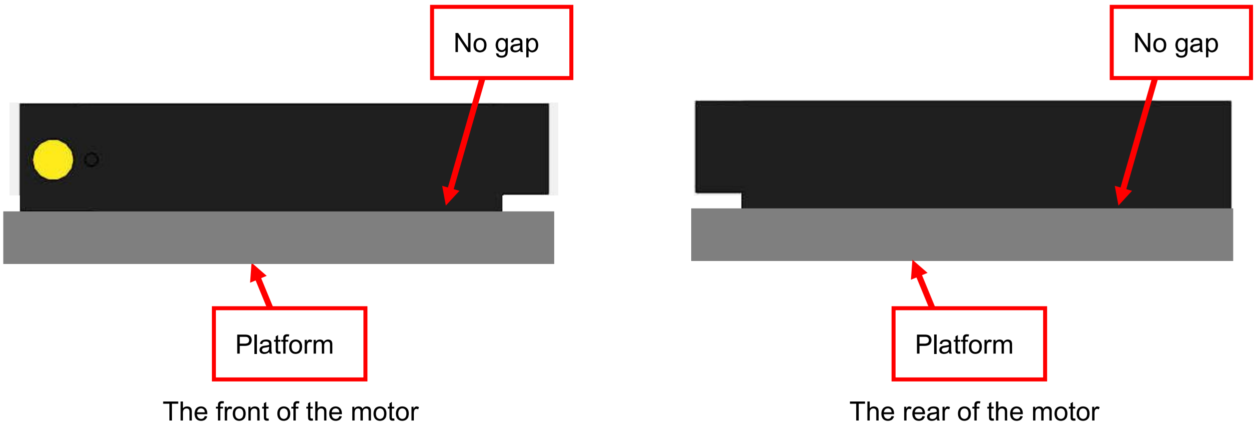


Figure 5.1-9 Forcer gap illustration

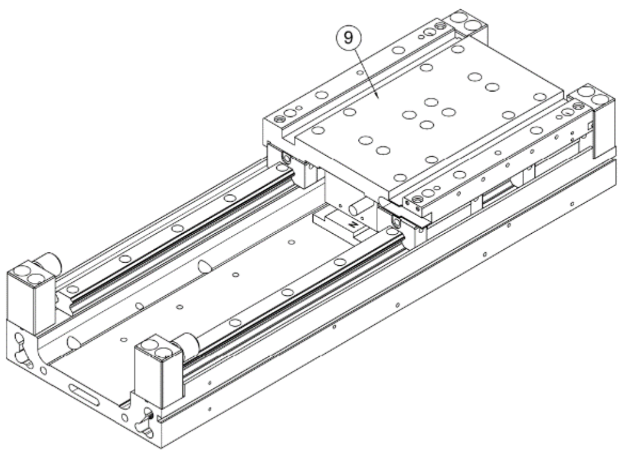


Figure5.1-10 Forcer base movement

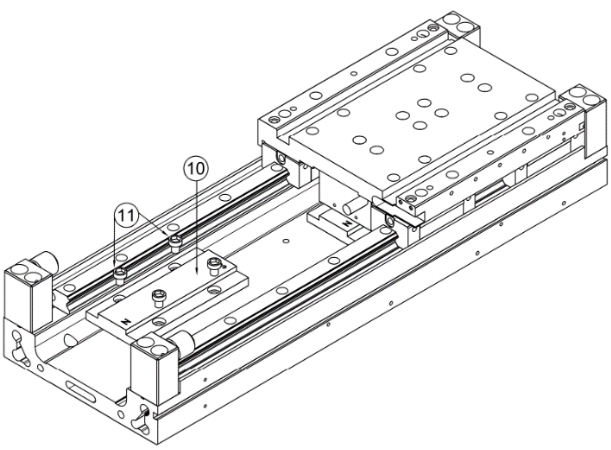
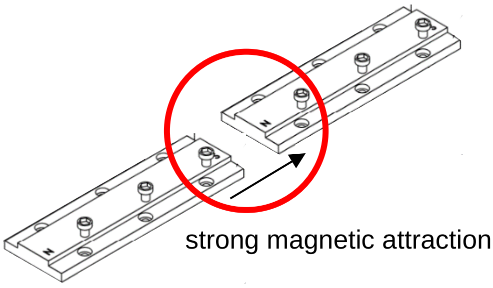
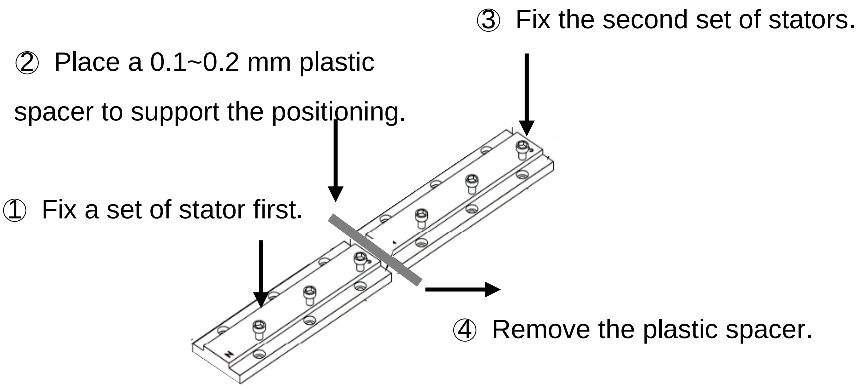


Figure5.1-11 Stator installation



There is a strong magnetic attraction between stators, personnel must pay attention it to avoid one's hand from having a pinch injury

Figure 5.1-12 Please be aware of the strong magnetic attraction force between the stators in order to prevent clamping injury of personnel hands.



Use a plastic stator to support the positioning while assembling multiple stators.

Figure 5.1-13 Recommended use of spacer to assist the positioning during fastening of a multiple set of stators.

NOTE Please prepare plastic spacer by customer.

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5.1.3 Precautions for installation of LMSC forcer and stator

⚠ **WARNING!**

Risk of damage to the motor assembly.

Beware the structural strength of the designed equipment because there is strong magnetic attraction between forcer and stator. Insufficient structural strength will lead to structure deformation. Too much installation tolerance will affect the adjusting performance of the equipment.

- There is a strong magnetic attraction force between the forcer and stator, and one side of the attraction force is at least 2850N.
- The installation structural strength at the two sides of the stators shall be considered in order to prevent any structural deformation due to the strong attraction force.
- When the gap between the forcer and stator is above 4.5 mm, the attracting force is close to 0.
- The polarity labels at the two sides of the stator shall be opposite from each other.
- Any uneven air gap in the LMSC magnetic brake linear motor can affect the attraction force between the forcer and stator. (refer to Figure5.1-26)

Step to assemble (stator)：

- Clean all installation surfaces first.
- Apply screw fixation gel onto all screws for fastening the stator. (refer to Figure5.1-14)
- Use non-magnetic material for spacing on top of the stator.
- Place the stator in position.
- Use a non-magnetic tool (refer to Figure 5.1-15) to install one side of the stators for half of the stroke.
- Place the non-magnetic object between the installation surfaces of the stators at two sides. (refer to Figure5.1-16)
- Use the non-magnetic tool to install the other side of the stators for half of the stroke. (refer to Figure 5.1-17)

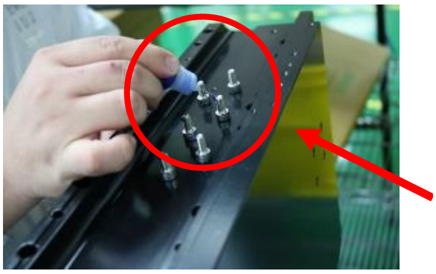


Figure5.1-14 Apply screw fixation gel

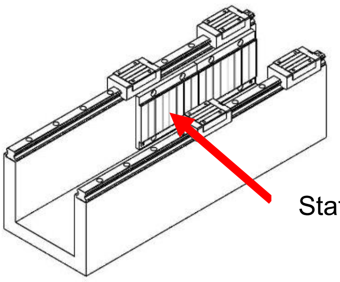


Figure 5.1-15 Use non-magnetic tool to install the stator

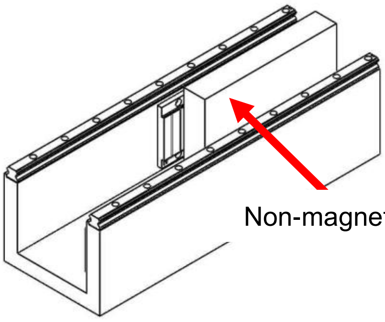


Figure5.1-16 Place the non-magnetic object

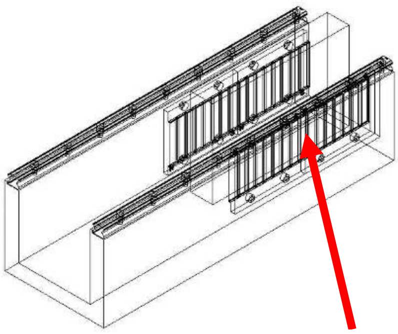


Figure 5.1-17 Use non-magnetic tool to install the stator

Step to assemble (forcer)：

- Install the forcer onto the forcer base first. (refer to Figure5.1-18)
- Install the force base onto the base sliding block. (refer to Figure5.1-19)
- Use thickness gauge to adjust the air gap (refer to Figure 5.1-20) to $\mathbf{0.75^{+0.25}_{-0.15}}$.

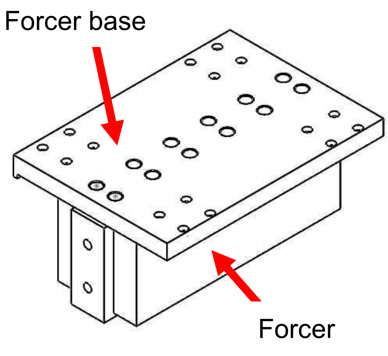


Figure5.1-18 Forcer installation

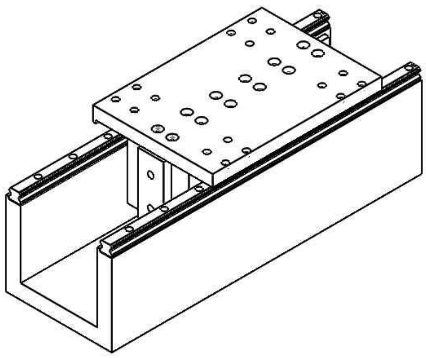


Figure5.1-19 Forcer base installation

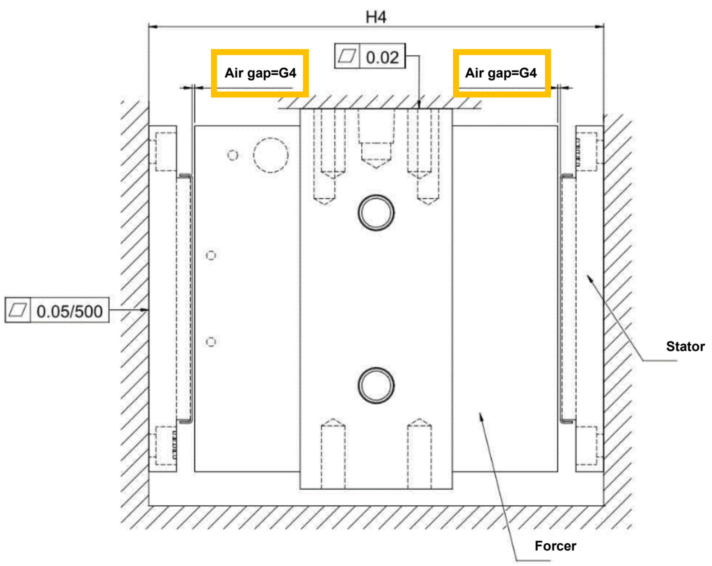


Figure 5.1-20 Air gap illustration

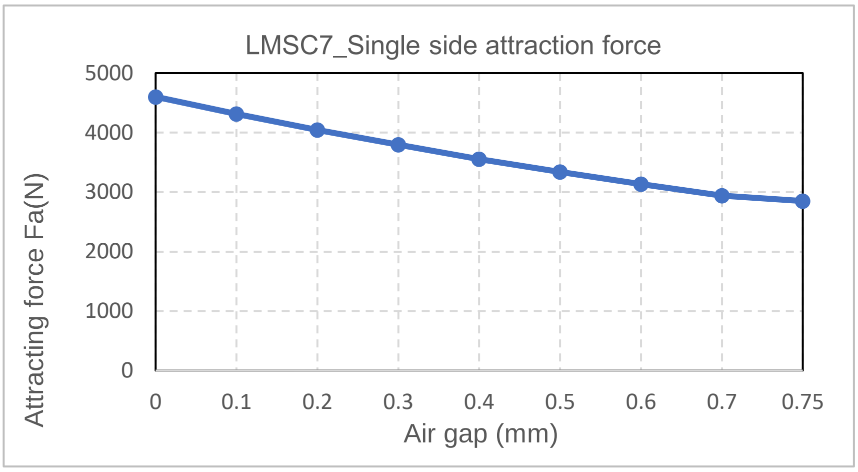


Figure 5.1-21 LMSC air gap-attracting force relationship graph

Table 5.1-1 Air gap-attracting force relationship chart

Air gap (mm)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.75
Single side attracting force F_a (N)	4601	4313	4042	3796	3556	3338	3134	2942	2850

Step to assemble (Remaining stator)：

- Move the forcer base to install the remaining stators. (refer to Figure5.1-22)
- Use the non-magnetic tool to install one side of the stators for half of the stroke. (refer to Figure5.1-23)
- Place the non-magnetic object between the installation surfaces of the stators at two sides. (refer to Figure5.1-24)
- Use the non-magnetic tool to install the other side of the stators for half of the stroke. (refer to Figure5.1-25)

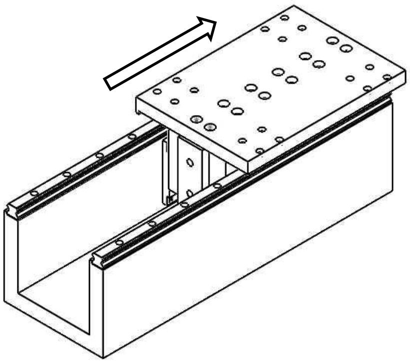


Figure5.1-22　Forcer base movement

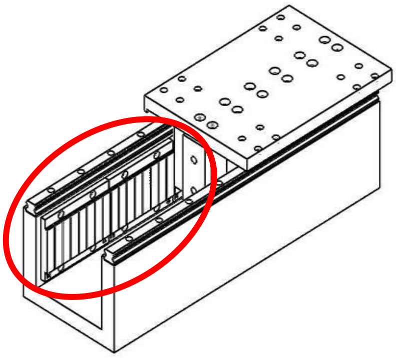


Figure5.1-23　Install one side of stators

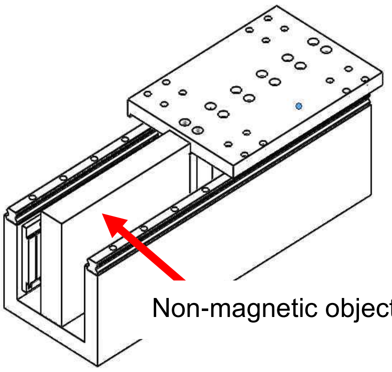


Figure5.1-24　Place the non-magnetic object

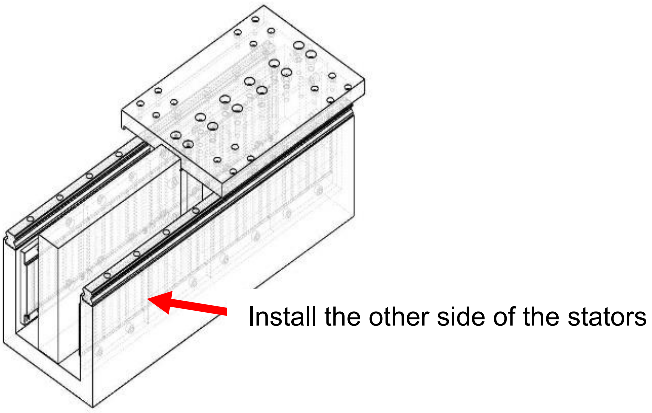


Figure5.1-25 Install the other side of stators

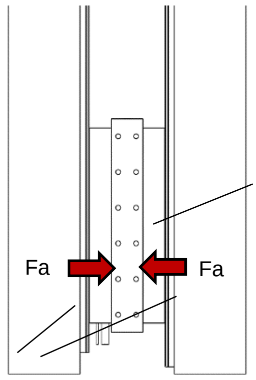


Figure5.1-26 LMSC force and stator installation illustration

Table 5-1-2 LMSC uneven air gap-attraction force correspondence chart

Air gap 1 (mm)	0	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75
Air gap 2 (mm)	1.5	1.45	1.35	1.25	1.15	1.05	0.95	0.85	0.75
Attracting force F_a (N)	2838	2633	2230	1840	1461	1090	724	361	0

5.2 Ironless linear motor installation

5.2.1 Precautions for installation of the LMC forcer and stator

⚠ WARNING!

Risk of forcer and stator assembly.
Prevent any hand clamping injury when you apply the products.

- Please handle the stator assembly carefully to prevent any hand clamping injury.

ATTENTIION!

- The stator warning label shall face upward
- After the installation of the stator assembly according to Section 4.2, please pay special attention to the gap between the stators.
- For the screw torque for fastening the forcer and stator assembly, please refer to Section 9.1.2.
- For the selection of the screw length and thread depth, please refer to Section 9.1.2.

Step to assemble：

- Use clean wiping cloth to dip with alcohol (95% industrial alcohol), and clean the installation interface. (refer to Figure5.2-1)
- Use screws ① to attach the stator assembly ② at the right most side onto the baseplate ③.(refer to Figure5.2-2)
- Use screws ④ to install the forcer base ⑤ onto the linear sliding block ⑥. (refer to Figure5.2-3)
- Move the forcer base ⑦ to the left most side to facilitate the fastening of the forcer assembly ⑧. (refer to Figure5.2-4)
- Move the forcer assembly ⑨ installed properly to the right side, and determine whether there is any interference in the forcer and stator assembly in order to be ready for the installation of the next set of stator. (refer to Figure5.2-5)
- Fasten the remaining stator assemblies ⑩ onto the baseplate ⑪. (refer to Figure5.2-6)
- After the installation is complete, move, and slide the forcer base to confirm that there is no interference. (refer to Figure5.2-7)

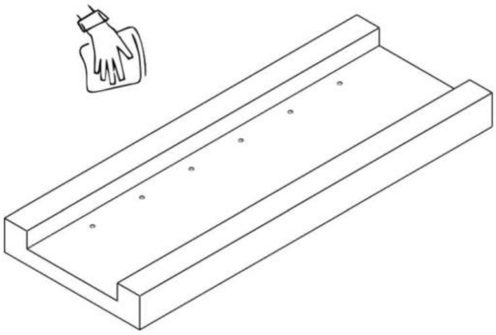


Figure5.2-1　Clean the installation interface

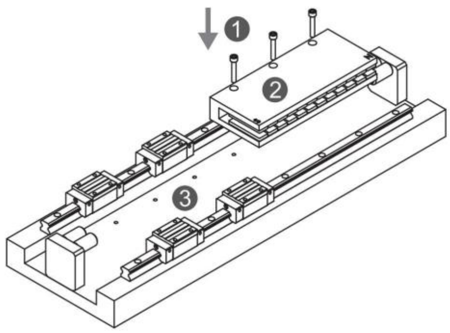


Figure5.2-2　Stator installation

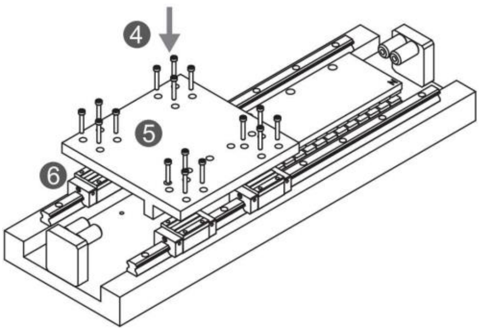


Figure5.2-3　Forcer base installation

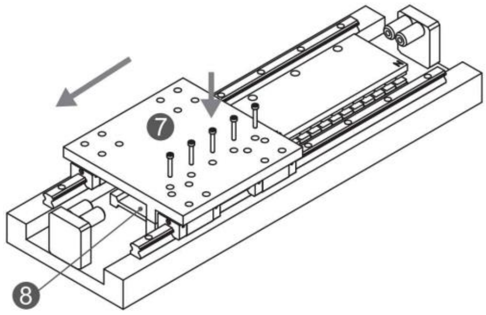


Figure5.2-4　Move the forcer base

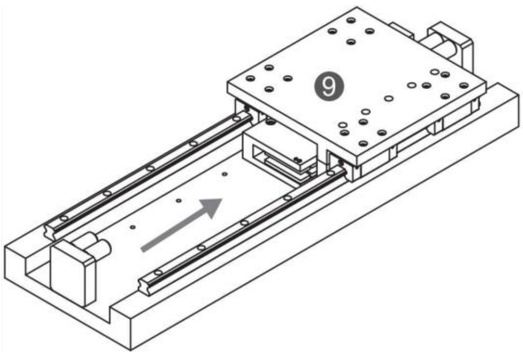


Figure5.2-5　Forcer installation

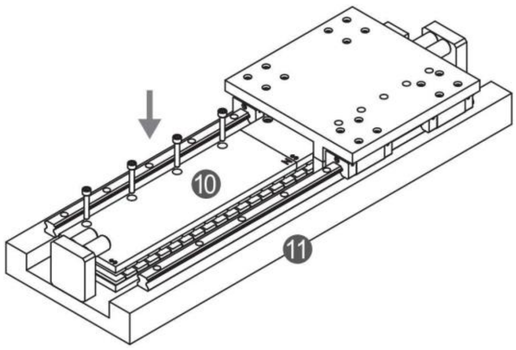


Figure5.2-6　Stator installation

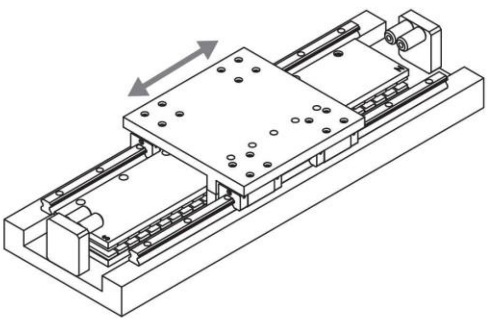


Figure5.2-7　Smoothness confirmation

5.2.2 Precautions for installation of LMT forcer and stator

⚠ WARNING!

Risk of forcer and stator assembly.
Prevent any hand clamping injury when you apply the products.
- Please handle the stator assembly carefully to prevent any hand clamping injury.

ATTENTION!

Risk of forcer and stator assembly.
For stator and forcer installation, beware the abnormal gap between units.
- After the installation of the forcer assembly according to Section 4.3, the concentricity shall not be greater than 0.2mm.
- After the installation of the stator assembly according to Section 4.3, please pay special attention to the gap between the stators.
- For the screw torque for fastening the forcer and stator assembly, please refer to Section 9.1.2.
- For the selection of the screw length and thread depth, please refer to Section 9.1.2.

Step to assemble：

- Use clean wiping cloth to dip with alcohol (95% industrial alcohol), and clean the stator assembly. (refer to Figure5.2-8)
- Place the forcer assembly ① onto the stator assembly ②. (refer to Figure5.2-9)
- Use screws ③ to install the stator assembly ④ onto the fixation base ⑤, and measure the height difference and the left and right difference, and such difference shall not be greater than 0.2mm. (refer to Figure5.2-10)
- Use screws ⑥ to install the forcer base ⑦ onto the sliding block ⑧. (refer to Figure5.2-11)
- Use screws ⑨ to fasten the forcer assembly ⑩ onto the forcer base ⑪.(refer to Figure5.2-12)
- After the installation is complete, move, and slide the forcer base to confirm that there is no interference. (refer to Figure5.2-13)

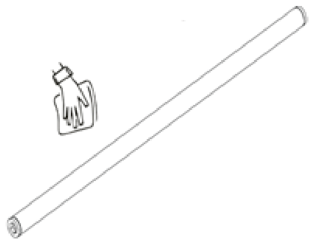


Figure5.2-8　Clean the installation interface

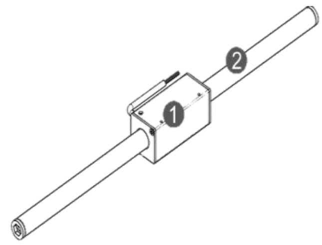


Figure5.2-9　Assemble the force and stator

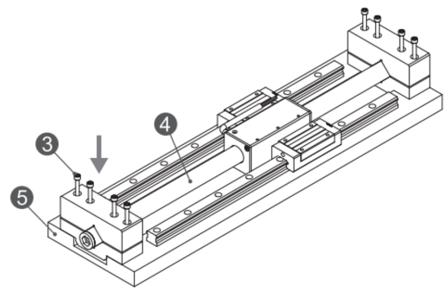


Figure5.2-10　Stator installation

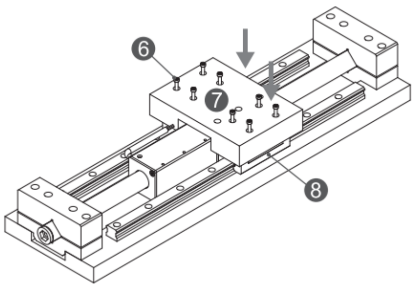


Figure5.2-11　Forcer base installation

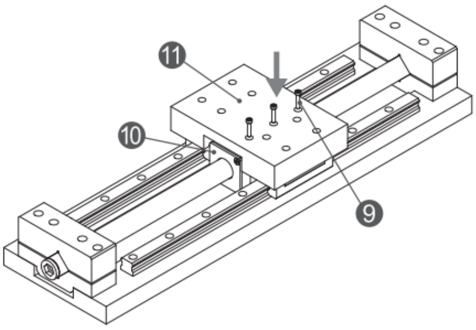


Figure5.2-12　Forcer installation

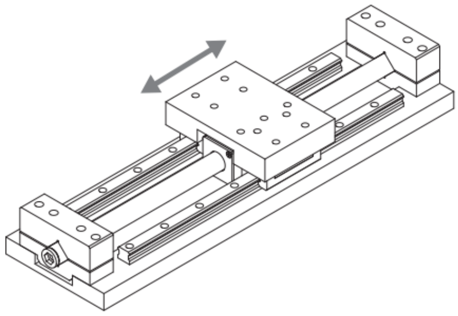


Figure5.2-13　Smoothness confirmation

5.3 Water-cooling linear motor cooling system installation

5.3.1 Forcer and stator precision water-cooling installation

Step to assemble (Forcer precision water-cooling)：(refer to Figure5.3-1~Figure5.3-2)

- Place the forcer precision water-cooling ② on top of the forcer ③, and the hole positions of the two objects shall be aligned and the direction shall be consistent.
- After aligning the hole positions of the forcer base ① and forcer precision water-cooling ② with the forcer ③, then perform installation.
- After the fastening is complete, it can then be installed onto the working platform sliding block. Please refer to the instructions in Section 5.1.2.

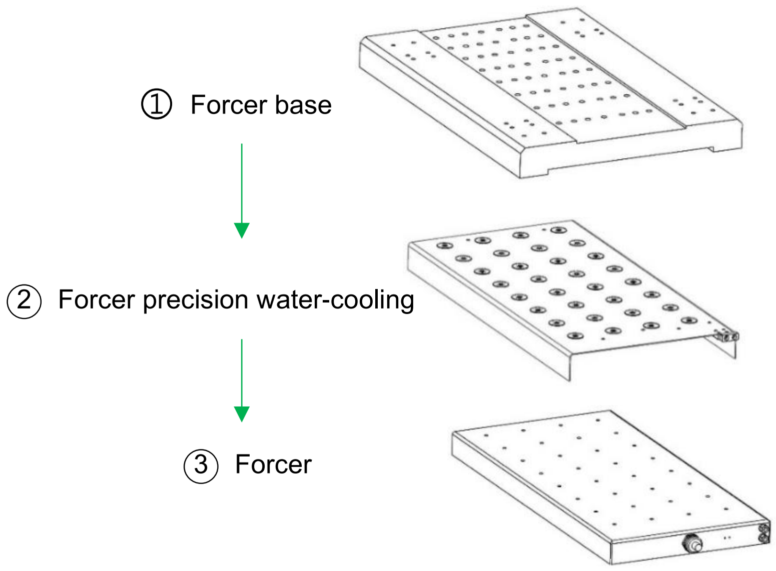


Figure5.3-1 Forcer precision water-cooling installation illustration

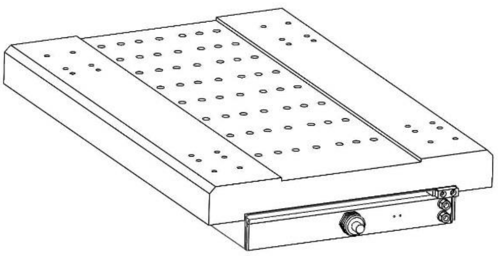


Figure5.3-2 Forcer precision water-cooling installation completion view

Step to assemble (Stator precision water-cooling)：(refer to Figure5.3-3)

- Fasten the connecting base ① at one side onto the working position of the operating platform.
- Insert the cooling pipes ② into the connecting base ① on the platform.
- If the length of the stator ⑤ is longer, then use the joint method to connect the cooling pipes ②.
- After all cooling pipes ② are installed completely, use the connecting base ⑥ at the other side for adjustment and fastening with the cooling pipes.
- Place the stator ⑤ at the corresponding position on the cooling pipes ②.
- Fasten all stators ⑤. For the fastening method of multiple sets of stators, please refer to the stator installation described in Section 5.1.2.

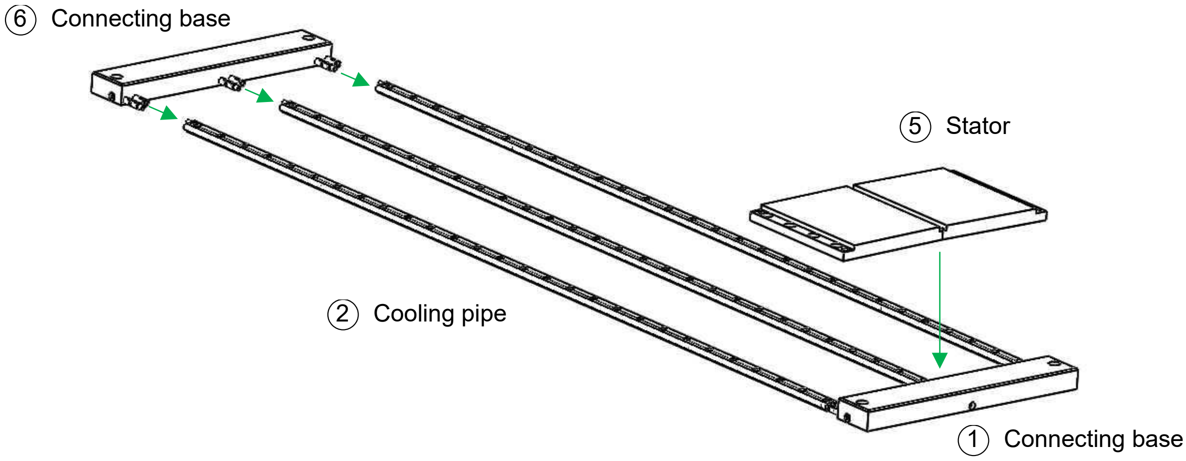


Figure5.3-3 Stator precision water-cooling installation illustration

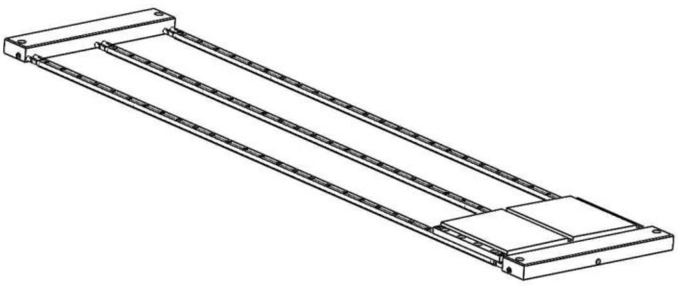


Figure5.3-4 Stator precision water-cooling installation completion view

5.3.2 Water-cooling motor quick connector installation

ATTENTION!

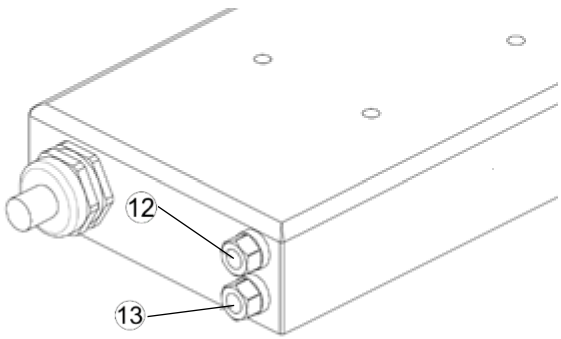
- When a quick connector of 1/8PT diameter is fastened onto the inlet or outlet, a white tape seal shall be wrapped around the connector in order to prevent any water leakage.
- When a quick connector of G1/8 diameter is fastened onto the inlet or outlet, with additional O-ring to prevent leakage.
- When a quick connector of PTFE coating on thread is fastened onto the inlet or outlet, a white tape seal is no need wrapped around the connector.
- The maximum pressure of the water-cooling loop is 10 bar.
- Use torque wrench (maximum torque shall not exceed 100 kgf-cm (9.8 Nm).
- If the above is not installed properly, it may cause damage, water leakage, or rupture of the water-cooling connector.
- All of the accessories provided on the factory product shall not be removed arbitrarily; otherwise, the product performance is not guaranteed.

LMFA series of forcer specification includes LMFA、LMFA-P and LMFP, and the pipe threads used are as shown in the table below:

Table 5.3-1 Forcer water-cooling connector threads

Forcer specification	Pipe thread
LMFA	1/8 PT
LMFA-P	G 1/8
LMFP	G 1/8
LMSC	1/8PT

Water-cooling connector ⑫ refers to the inlet, and water-cooling connector ⑬ refers to the outlet.



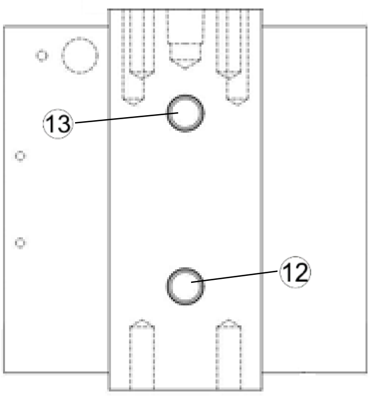


Figure5.3-5 Water-cooling connector installation location

5.3.3 Precision water-cooling motor quick connector installation

LMFC water-cooling motor quick connector installation

Water-cooling connector ⑫ refers to the inlet, and water-cooling connector ⑬ refers to the outlet, and both are G1/8.

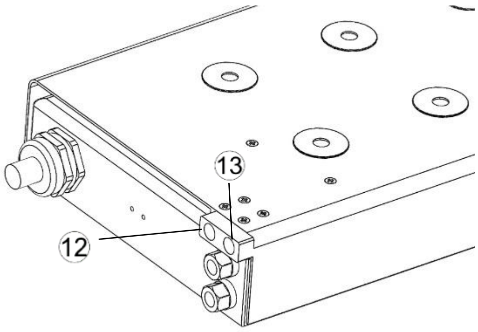


Figure5.3-6 Forcer precision water-cooling connector installation location

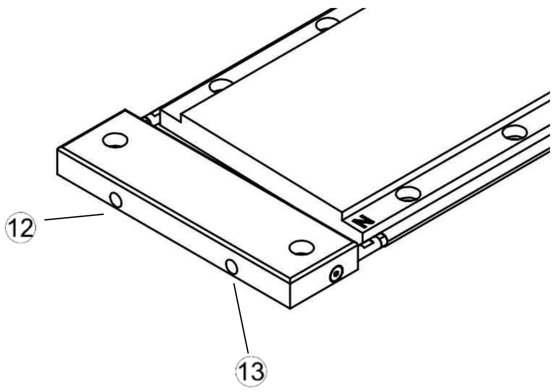


Figure5.3-7 Stator precision water-cooling connector installation location

6. Selection of Motor Accessory and Power Cable

6.1 Standard specification of power cable

The lengths of power cable and temperature cable for standard linear motor are from 0.5M to 1.2M. The unit of length for cable is 100mm. Cable outlets could be with connectors or with open ends as shown in Figure 6.1-1.

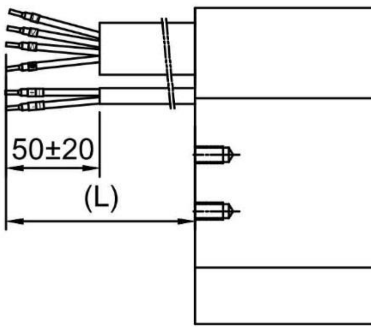


Figure 6.1-1 Outlet specifications for power cable

6.2 Recommended construction method for grounding protection

Shielding must be equipped with power cable or temperature cable. Also, the shielding must be grounded (as Figure 6.2-1 shows).

After stripping off the shielding, the whole shielding can be cut to an appropriate length for more convenient operations. Do not cut part of the shielding; otherwise, the shielding might break easily and effect the grounding efficiency.

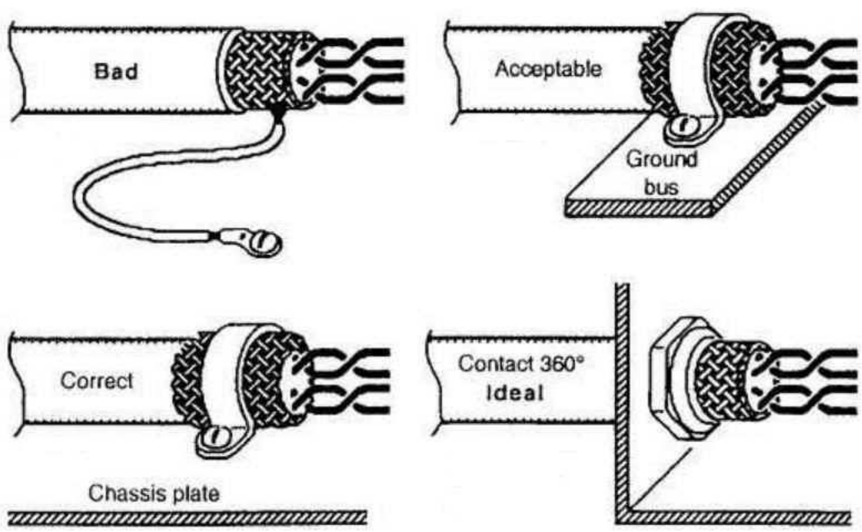


Figure 6.2-1 Recommended grounding method

6.2.1 Recommended construction method for ironless linear motor grounding protection

For the ironless linear motor power cable, it is recommended to use an isolation net for the grounding protection. The isolation net is divided into two parts, one part for the grounding, and the other part is wrapped with copper foil to connect to the metal casing, as shown in Figure6.2-2.

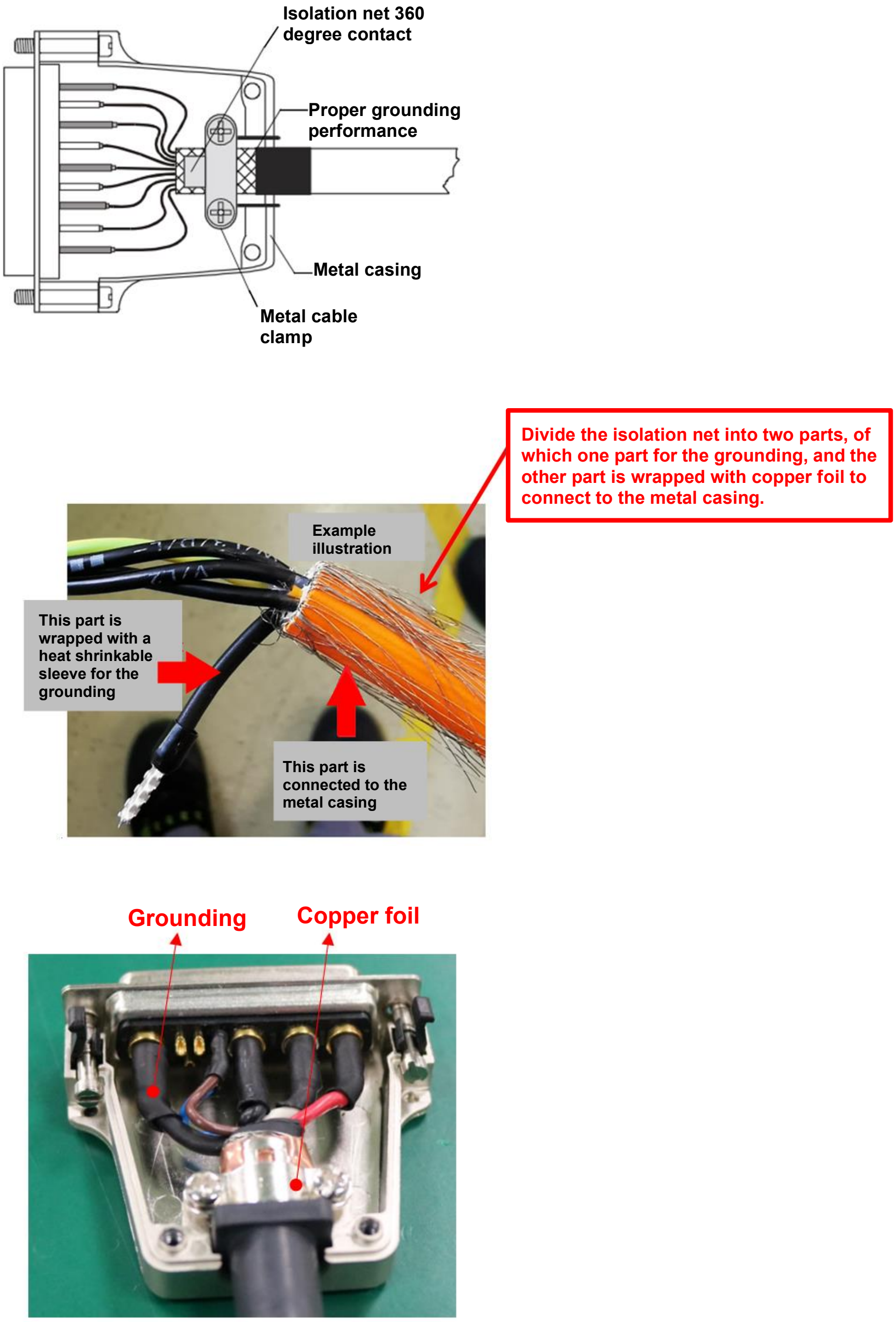


Figure6.2-2 ironless linear motor grounding protection

6.3 Recommended installation method of extension cable

6.3.1 LMSA-Z series

As iron core linear motor LMSA-Z series is equipped with connector, extension cable should be connected in actual application. It is recommended to use heat-shrink tubing during installation.

Put the heat-shrink tubing on the extension cable in advance (as Figure 6.3-1 shows). After connecting the extension cable to the motor (as Figure 6.3-2 shows), put the heat-shrink tubing on the connector (as Figure 6.3-3 shows), and shrink it with heat gun (as Figure 6.3-4 shows).

The motor cable should be fixed by cable tie and cable tray after assembling the forcer on the forcer plate. Also, the extension cable should be fixed by the cable tie and put into the cable chain to ensure it works in normal, as shown in Figure 6.3-5 and Figure 6.3-6.

If the cable doesn't be installed properly as shown in Figure 6.3-7 and Figure 6.3-8, failures such as shaking and worn-out might be happened and caused abnormal situation.

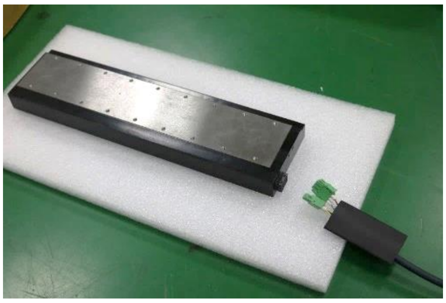


Figure 6.3-1 Put the heat-shrink tubing on the extension cable in advance

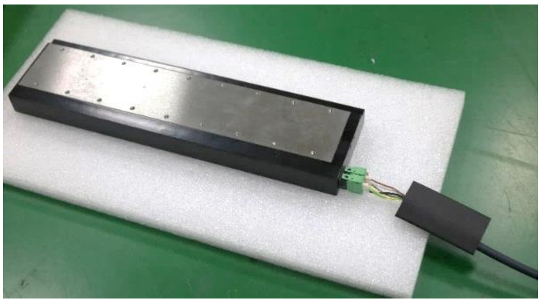


Figure 6.3-2 Connect the extension cable to the motor

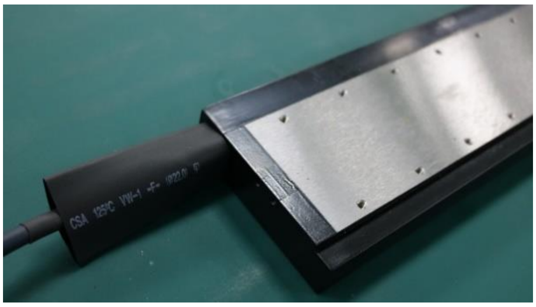


Figure 6.3-3 Put the heat-shrink tubing on the connector

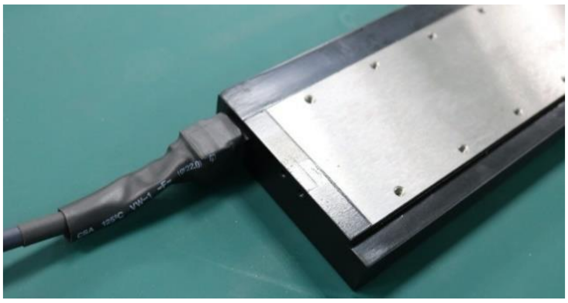


Figure 6.3-4 Shrink it with heat gun

■ Recommended installation method

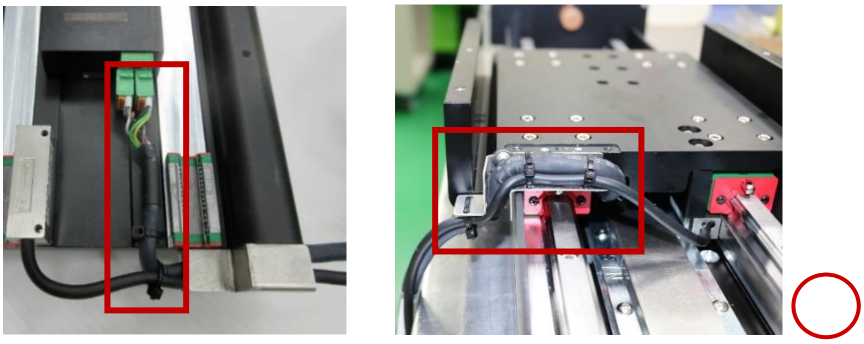


Figure 6.3-5 Fix the motor cable by cable tie and cable tray

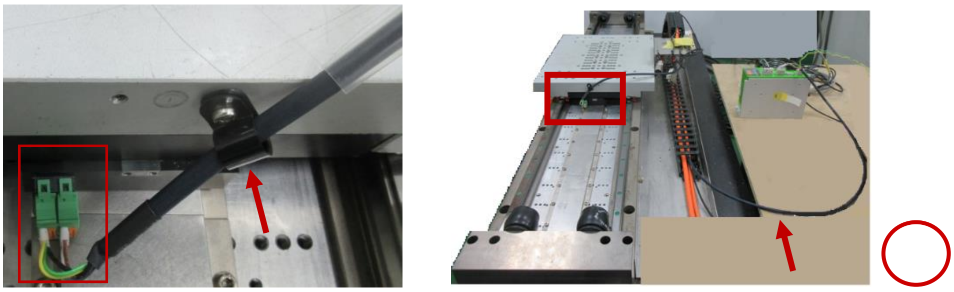


Figure 6.3-6 Fix the extension cable by cable tie and put into the cable chain

■ Improper installation method

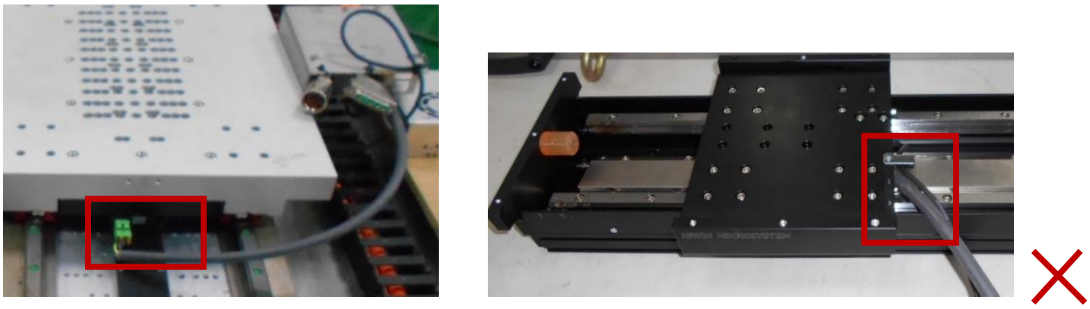


Figure 6.3-7 Extension cable is not fixed

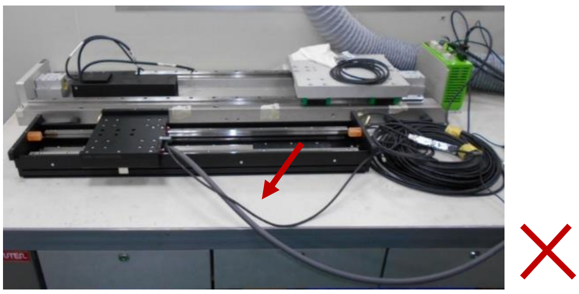


Figure 6.3-8 Extension cable is not put into the cable chain

6.3.2 Motor with connector series

For motor with standard connector, the recommended installation methods of standard extension cable are given as follows.

- Without copper pillar design: Customers get their own adaption board mounting bracket with 4 internal threads to make the screws be fixed.
- With copper pillar design: Customers adopt through-hole on their own adaption board mounting bracket to make the screws go through. HIWIN can offer copper pillar (the part shown in the red circle of Figure 6.3-9) to fix the connectors. If customers need the accessories, ask the sales representative to indicate the need on the order.
- Usage examples are described in Table 6.3-1。

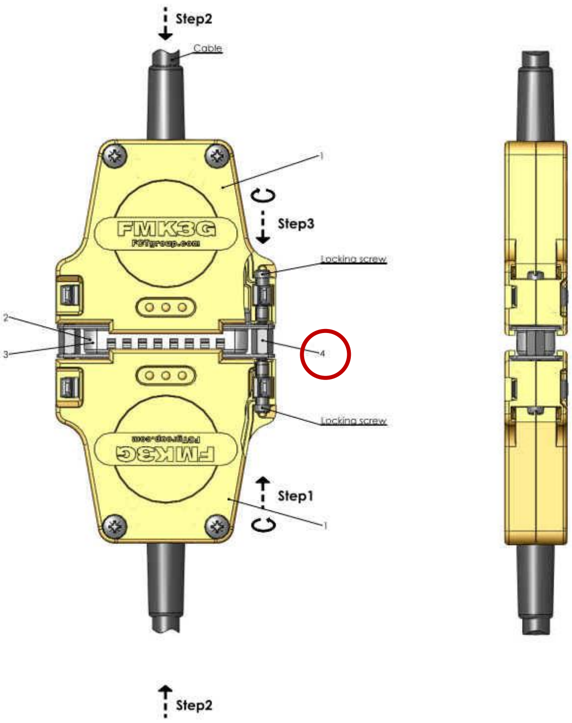
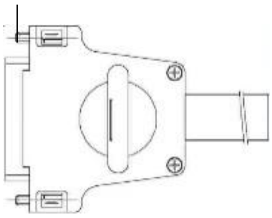
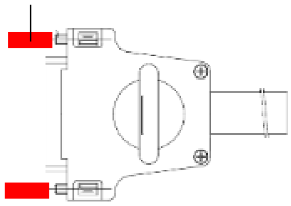
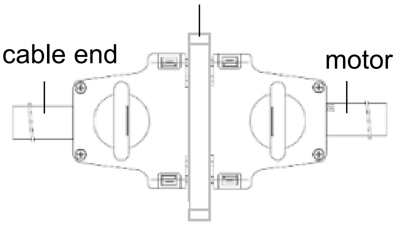
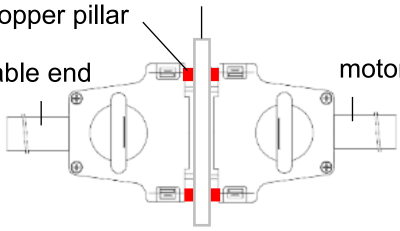


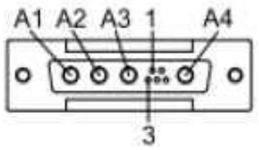
Figure 6.3-9 Connecting diagram

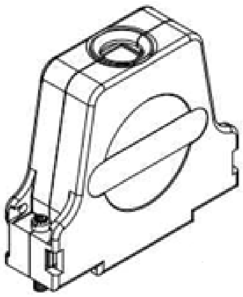
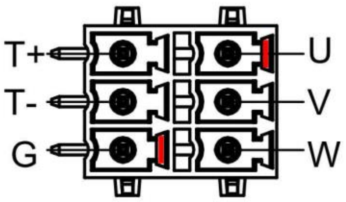
Table 6.3-1 Description for usage examples

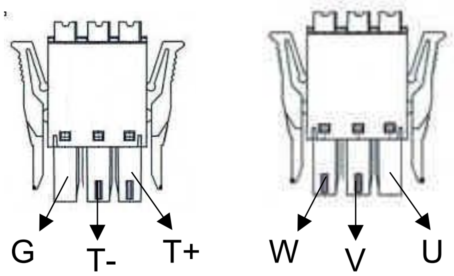
Standard：Without copper pillar design	With accessories：With copper pillar design
	
Example：Connect with mounting bracket	**Example：Connect with copper pillar**
	

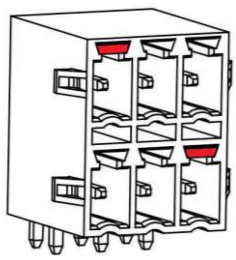
6.4 Connector selection and pin assignment

Table 6.4-1 Connection selection wiring chart

<table>
<tr><th>Model</th><th>Connector</th><th>Pin</th></tr>
<tr><td>LMSA series</td><td>


D-Sub 9-Pin Connector</td><td>
<table>
<tr><th colspan="2">Wiring Diagram</th></tr>
<tr><td>FMK3G(Male)</td><td>Signal</td></tr>
<tr><td>A1</td><td>V</td></tr>
<tr><td>A2</td><td>U</td></tr>
<tr><td>A3</td><td>W</td></tr>
<tr><td>A4</td><td>GND</td></tr>
<tr><td>1</td><td>T+</td></tr>
<tr><td>3</td><td>T-</td></tr>
<tr><td>CASE</td><td></td></tr>
</table>
</td></tr>
<tr><td>LMSA-Z series</td><td>




Pluggable Terminal Blocks</td><td>
<table>
<tr><th colspan="2">Pin Assignment</th></tr>
<tr><td>Pluggable Terminal Blocks</td><td>Cable Signal</td></tr>
<tr><td>U</td><td>U</td></tr>
<tr><td>V</td><td>V</td></tr>
<tr><td>W</td><td>W</td></tr>
<tr><td>T+</td><td>T+</td></tr>
<tr><td>T-</td><td>T-</td></tr>
<tr><td>G</td><td>G</td></tr>
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</td></tr>
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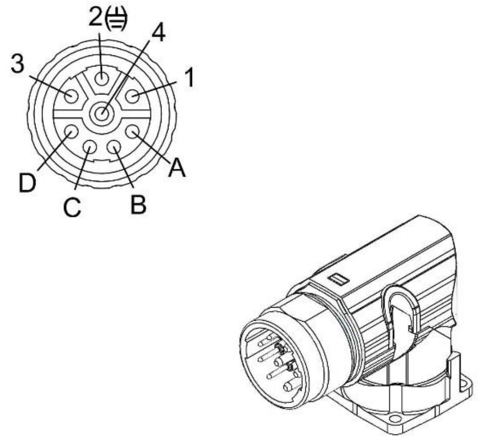
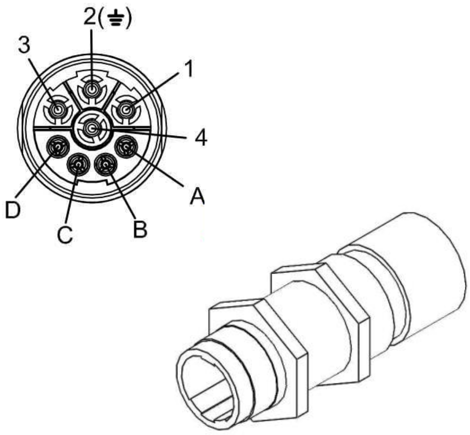
<table>
<tr>
<td rowspan="3">LMFA series
(M23)</td>
<td>

Metal connector (Angled Rotatable)</td>
<td>
<table>
<tr><th colspan="2">Wiring Table</th><th></th></tr>
<tr><th>Male</th><th>Signal</th><th></th></tr>
<tr><td>1</td><td>U</td><td></td></tr>
<tr><td>4</td><td>V</td><td></td></tr>
<tr><td>3</td><td>W</td><td></td></tr>
<tr><td>(2)⏚</td><td rowspan="2">⏚</td><td></td></tr>
<tr><td>Case</td><td></td></tr>
<tr><td>A</td><td>T1+(Gray)</td><td rowspan="2">PTC
SNM120</td></tr>
<tr><td>B</td><td>T1-(Gray)</td></tr>
<tr><td>C</td><td>T2+(Red)</td><td rowspan="2">Pt1000</td></tr>
<tr><td>D</td><td>T2-(White)</td></tr>
</table>
</td>
</tr>
<tr>
<td>

Metal connector</td>
<td>
<table>
<tr><th colspan="2">Wiring Table</th><th></th></tr>
<tr><th>Male</th><th>Signal</th><th></th></tr>
<tr><td>1</td><td>U</td><td></td></tr>
<tr><td>4</td><td>V</td><td></td></tr>
<tr><td>3</td><td>W</td><td></td></tr>
<tr><td>(2)⏚</td><td rowspan="2">⏚</td><td></td></tr>
<tr><td>Case</td><td></td></tr>
<tr><td>A</td><td>T1+(Gray)</td><td rowspan="2">PTC
SNM120</td></tr>
<tr><td>B</td><td>T1-(Gray)</td></tr>
<tr><td>C</td><td>T2+(Red)</td><td rowspan="2">Pt1000</td></tr>
<tr><td>D</td><td>T2-(White)</td></tr>
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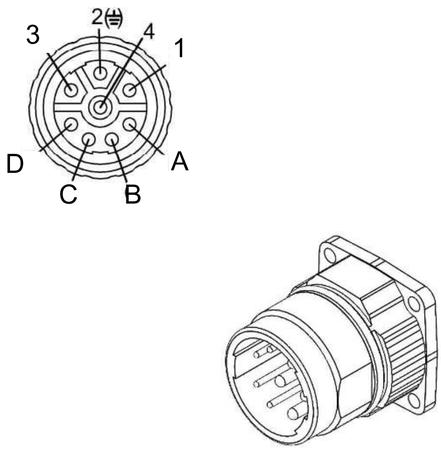
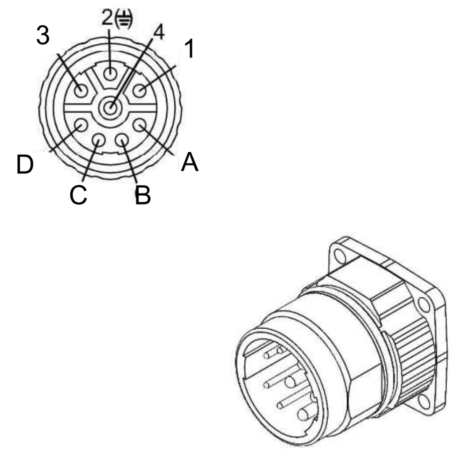
<tr>
<td>

Metal connector</td>
<td>
<table>
<tr><th colspan="2">Wiring Table</th><th></th></tr>
<tr><th>Male</th><th>Signal</th><th></th></tr>
<tr><td>1</td><td>U</td><td></td></tr>
<tr><td>4</td><td>V</td><td></td></tr>
<tr><td>3</td><td>W</td><td></td></tr>
<tr><td>2(⏚)</td><td rowspan="2">⏚</td><td></td></tr>
<tr><td>Case</td><td></td></tr>
<tr><td>A</td><td>T1+</td><td rowspan="2">PTC
SNM120</td></tr>
<tr><td>B</td><td>T1-</td></tr>
<tr><td>C</td><td>T2+</td><td rowspan="2">Pt1000</td></tr>
<tr><td>D</td><td>T2-</td></tr>
</table>
</td>
</tr>
</table>

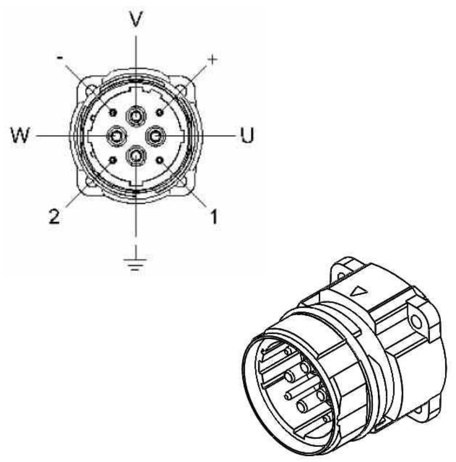
LMFP series



Metal connector (M23)

Wiring Table	
Male	Signal
1	U
4	V
3	W
2(⏚) / Case	⏚
A	T1+
B	T1-
C	T2+
D	T2-

A/B (T1+/T1-): PTC SNM120
C/D (T2+/T2-): Pt1000

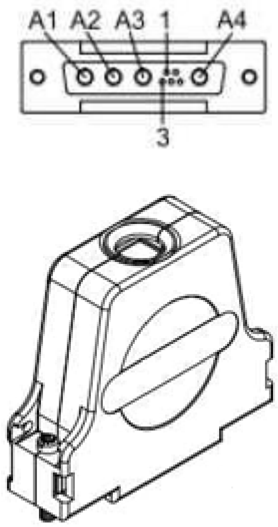


Metal connector (M40)

Wiring Table	
Male	Signal
U	U
V	V
W	W
⏚ / Case	⏚
1	T1+
2	T1-
+	T2+
-	T2-

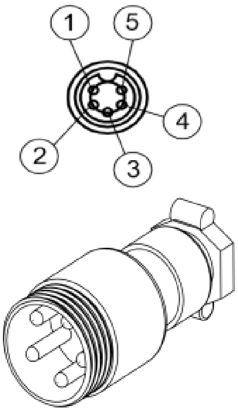
1/2 (T1+/T1-): PTC SNM120
+/- (T2+/T2-): Pt1000

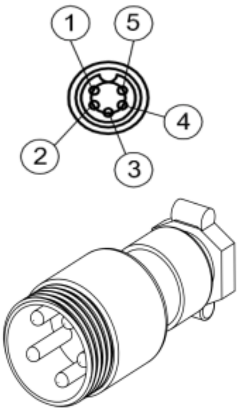
LMSC7

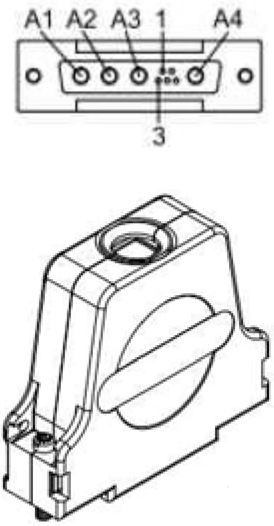


D-Sub 9-Pin Connector

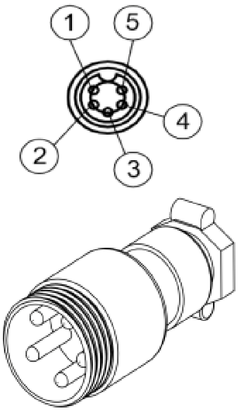
Wiring Diagram	
FMK3G(Male)	Signal
A1	V
A2	U
A3	W
A4	GND
1	T+
3	T-
CASE	

<table>
<tr>
<td>LMSS11</td>
<td>

M16-P5P (Male)</td>
<td>
<table>
<tr><th colspan="2">Wiring Diagram</th></tr>
<tr><th>Male</th><th>Signal</th></tr>
<tr><td>1</td><td>V</td></tr>
<tr><td>2</td><td>U</td></tr>
<tr><td>3</td><td>W</td></tr>
<tr><td>Case</td><td>GND</td></tr>
<tr><td>4</td><td>T+</td></tr>
<tr><td>5</td><td>T-</td></tr>
</table>
</td>
</tr>
<tr>
<td>LMC
A/B/C/D/E/
EFC/HUB</td>
<td>

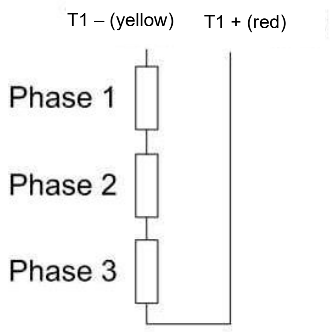
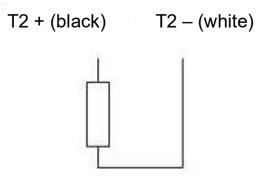
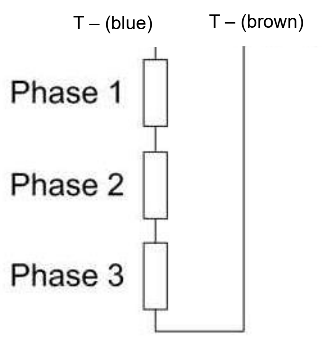
M16-P5P (Male)</td>
<td>
<table>
<tr><th colspan="2">Wiring Diagram</th></tr>
<tr><th>Male</th><th>Signal</th></tr>
<tr><td>1</td><td>V</td></tr>
<tr><td>2</td><td>U</td></tr>
<tr><td>3</td><td>W</td></tr>
<tr><td>Case</td><td>GND</td></tr>
<tr><td>4</td><td>T+</td></tr>
<tr><td>5</td><td>T-</td></tr>
</table>
</td>
</tr>
<tr>
<td>LMC
F/EFE/EFF</td>
<td>

D-Sub 9-Pin Connector</td>
<td>
<table>
<tr><th colspan="2">Wiring Diagram</th></tr>
<tr><th>FMK3G(Male)</th><th>Signal</th></tr>
<tr><td>A1</td><td>V</td></tr>
<tr><td>A2</td><td>U</td></tr>
<tr><td>A3</td><td>W</td></tr>
<tr><td>A4</td><td>GND</td></tr>
<tr><td>1</td><td>T+</td></tr>
<tr><td>3</td><td>T-</td></tr>
<tr><td>CASE</td><td></td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td>LMT
2/6/A/B/C</td>
<td>
M16-P5P (Male)</td>
<td>
<table>
<tr><th colspan="2">Wiring Diagram</th></tr>
<tr><th>Male</th><th>Signal</th></tr>
<tr><td>1</td><td>V</td></tr>
<tr><td>2</td><td>U</td></tr>
<tr><td>3</td><td>W</td></tr>
<tr><td>Case</td><td>GND</td></tr>
<tr><td>4</td><td>T+</td></tr>
<tr><td>5</td><td>T-</td></tr>
</table>
</td>
</tr>
</table>

6.5 Configuration of over-temperature protection

Table 6.5-1 Over-temperature protection configuration chart

	Configuration diagram
PTC SNM120	
PT1000	
SKM120	

6.6 Hall sensor

WARNING!

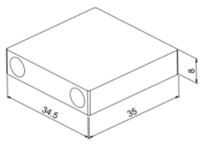
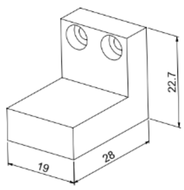
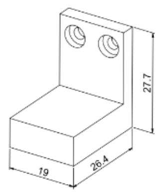
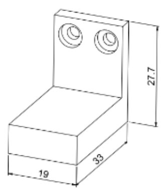
Risk of injury from uncontrolled motor movements!

An incorrectly installed or connected Hall sensor may cause uncontrolled motor movements which can lead to injuries or might damage the machine.

- Hall sensor may only be connected by specialist personnel.

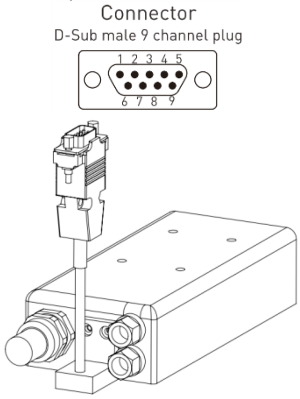
For the driving control of a linear motor, Hall sensors can be selected and purchased to find the optimal electrical angle. Hall sensors can be divided into digital and Analog sensors according to the signal output method. A digital hall sensor has relatively better anti-interference capability; however, it has a maximum electrical angle error of 30° . An Analog Hall sensor is prone to be affected by interference; nonetheless, it has no electrical angle error. The following provides further description on the hall sensors for iron core and ironless linear motors respectively.

Table 6.6-1 Hall sensor specification comparison chart with digital signal for iron core linear motors

Hall sensor specification	Output signal	Outlet mode	Hall sensor Illustration of dimensions	Applicable linear motor series
LMAHS	Digital	Connector		LMS Series
LMAHS-W	Digital	Bare cable		
LMAHSA	Digital	Connector		LMSA Series
LMAHSA-W	Digital	Bare cable		
LMAHF1	Digital	Connector		LMFA0~2 Series
LMAHF1-W	Digital	Bare cable		
LMAHF2	Digital	Connector		LMFA3~6 Series
LMAHF2-W	Digital	Bare cable		

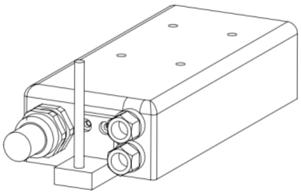
Outlet mode and signal pin illustration

Example 1: Connector outlet mode and signal cable pin illustration



Signal cable	
Signal	Color
Vcc	1
Hall A(out)	2
Hall B(out)	3
Hall C(out)	4
GND	5
⏚	Casing

Example 2: Bare cable outlet mode and signal cable pin illustration



Signal cable	
Signal	Color
Vcc	Brown
Hall A(out)	White
Hall B(out)	Gray
Hall C(out)	Yellow
GND	Green
⏚	Isolation net

NOTE In the example 2, the signal cable pin not include the type of LMAHF2 and LMAHF2-W.
NOTE The signal cable pin of LMAHF2 and LMAHF2-W as follow.

Signal cable		
Signal	Color	Color
Vcc	Brown	1
Hall B(out)	White	2
Hall C(out)	Gray	3
Hall A(out)	Yellow	4
GND	Green	5
⏚	Shield	Casing

Table 6.6-2　Hall sensor specification comparison chart with Analog signal for iron core linear motors

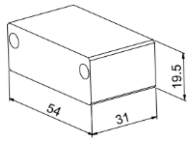
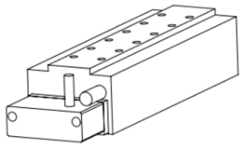
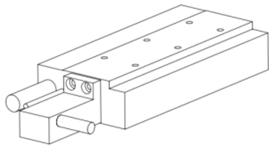
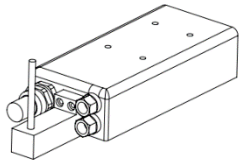
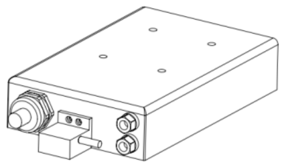
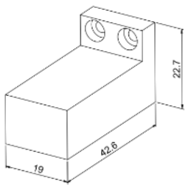
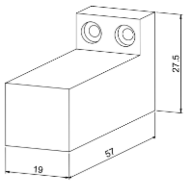
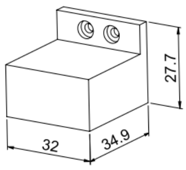
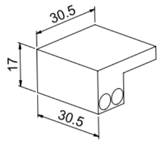
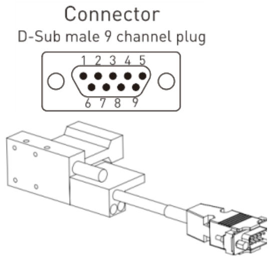
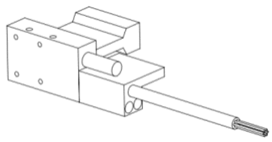
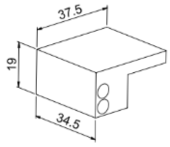
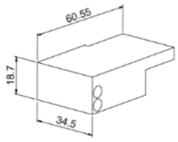
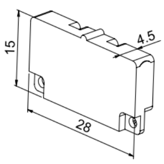
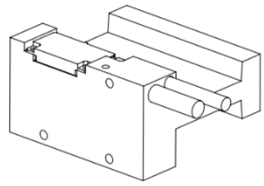
<table>
<tr><th>Hall sensor specification</th><th>Output signal</th><th>Outlet mode</th><th>Hall sensor Illustration of dimensions</th><th>Applicable linear motor series</th><th>Outlet mode and signal pin illustration</th></tr>
<tr><td>LMAHSA-D</td><td>Analog</td><td>Bare cable</td><td>
</td><td>LMS Series</td><td rowspan="4">Example: Analog output signal bare cable mode and signal cable pin illustration




<table>
<tr><th colspan="2">Signal cable</th></tr>
<tr><td>Signal</td><td>Color</td></tr>
<tr><td>Vcc</td><td>Brown</td></tr>
<tr><td>A+</td><td>Red</td></tr>
<tr><td>A-</td><td>Blue</td></tr>
<tr><td>B+</td><td>Yellow</td></tr>
<tr><td>B-</td><td>Green</td></tr>
<tr><td>GND</td><td>White</td></tr>
<tr><td>⏚</td><td>Isolation net</td></tr>
</table></td></tr>
<tr><td>LMAHSAA-D</td><td>Analog</td><td>Bare cable</td><td>
</td><td>LMSA Series</td></tr>
<tr><td>LMAHFA1-D</td><td>Analog</td><td>Bare cable</td><td>
</td><td>LMFA0~2 series</td></tr>
<tr><td>LMAHFA2-D</td><td>Analog</td><td>Bare cable</td><td>
</td><td>LMFA3~6 series</td></tr>
</table>

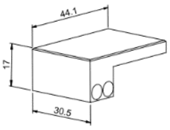
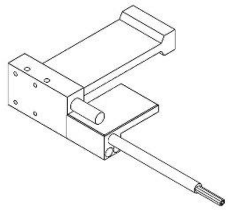
Table 6.6-3 Hall sensor specification comparison chart with digital signal for LMC

<table>
<tr><th>Hall sensor specification</th><th>Output signal</th><th>Outlet mode</th><th>Hall sensor Illustration of dimensions</th><th>Applicable linear motor series</th><th>Outlet mode and signal pin illustration</th></tr>
<tr><td>LMAHC</td><td>Digital</td><td>Connector</td><td rowspan="2"></td><td rowspan="2">LMCA/LMCB/ LMCC series</td><td rowspan="4">Example 1: Connector outlet mode and signal cable pin illustration


<table>
<tr><th colspan="2">Signal cable</th></tr>
<tr><th>Signal</th><th>Connector</th></tr>
<tr><td>Vcc</td><td>1</td></tr>
<tr><td>Hall A(out)</td><td>2</td></tr>
<tr><td>Hall B(out)</td><td>3</td></tr>
<tr><td>Hall C(out)</td><td>4</td></tr>
<tr><td>GND</td><td>5</td></tr>
<tr><td>⏚</td><td>Casing</td></tr>
</table>
Example 2: Bare cable outlet mode and signal cable pin illustration

<table>
<tr><th colspan="2">Signal cable</th></tr>
<tr><th>Signal</th><th>Color</th></tr>
<tr><td>Vcc</td><td>Brown</td></tr>
<tr><td>Hall A(out)</td><td>White</td></tr>
<tr><td>Hall B(out)</td><td>Gray</td></tr>
<tr><td>Hall C(out)</td><td>Yellow</td></tr>
<tr><td>GND</td><td>Green</td></tr>
<tr><td>⏚</td><td>Isolation net</td></tr>
</table></td></tr>
<tr><td>LMAHC-W</td><td>Digital</td><td>Bare cable</td></tr>
<tr><td>LMAHC2</td><td>Digital</td><td>Connector</td><td rowspan="2"></td><td rowspan="2">LMCD/LMCE Series</td></tr>
<tr><td>LMAHC2-W</td><td>Digital</td><td>Bare cable</td></tr>
<tr><td>LMAHC3</td><td>Digital</td><td>Connector</td><td rowspan="2"></td><td rowspan="2">LMCF series</td><td rowspan="2"></td></tr>
<tr><td>LMAHC3-W</td><td>Digital</td><td>Bare cable</td></tr>
<tr><td>LMAHEF3-W</td><td>Digital</td><td>Bare cable</td><td></td><td>LMC-EFC/ LMC-EFE/ LMC-EFF series</td><td>Example : Bare cable outlet mode and signal cable pin illustration

<table>
<tr><th colspan="2">Signal cable</th></tr>
<tr><th>Signal</th><th>Color</th></tr>
<tr><td>Vcc</td><td>Brown</td></tr>
<tr><td>Hall A(out)</td><td>White</td></tr>
<tr><td>Hall B(out)</td><td>Gray</td></tr>
<tr><td>Hall C(out)</td><td>Yellow</td></tr>
<tr><td>GND</td><td>Green</td></tr>
<tr><td>⏚</td><td>Isolation net</td></tr>
</table></td></tr>
</table>

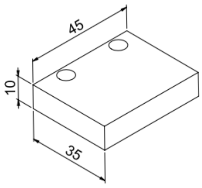
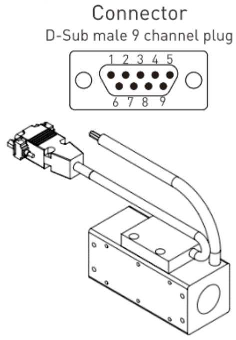
NOTE LMAHEF3-W are not sold separately, and it is necessary to place orders together with the corresponding forcer series. This Hall sensor is shipped after it is fastened onto the forcer.

Table 6.6-4 Hall sensor specification comparison chart with Analog signal for LMC

Hall sensor specification	Output signal	Outlet mode	Hall sensor Illustration of dimensions	Applicable linear motor series	Outlet mode and signal pin illustration
LMAHCA-D	Analog	Bare cable		LMCA/ LMCB/ LMCC series	Example 1: Bare cable outlet mode and signal cable pin illustration 

Signal cable	
Signal	Color
Vcc	Brown
A+	Red
A-	Blue
B+	Yellow
B-	Green
GND	White
⏚	Isolation net

Table 6.6-5 Hall sensor specification comparison chart with digital signal for LMT

<table>
<tr><th>Hall sensor specification</th><th>Output signal</th><th>Outlet mode</th><th>Hall sensor Illustration of dimensions</th><th>Applicable linear motor series</th><th>Outlet mode and signal pin illustration</th></tr>
<tr><td>LMDHTA</td><td>Digital</td><td>Connector</td><td rowspan="2">
</td><td rowspan="2">LMTA Series</td><td rowspan="4">Example 1: Connector outlet mode and signal cable pin illustration


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<tr><th colspan="2">Signal cable</th></tr>
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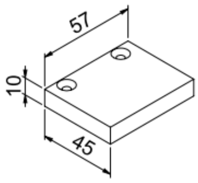
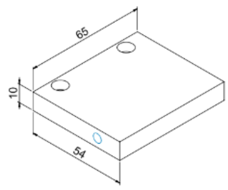
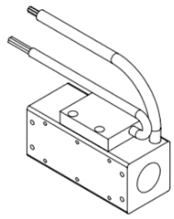
<tr><td>Vcc</td><td>1</td></tr>
<tr><td>Hall A(out)</td><td>2</td></tr>
<tr><td>Hall B(out)</td><td>3</td></tr>
<tr><td>Hall C(out)</td><td>4</td></tr>
<tr><td>GND</td><td>5</td></tr>
<tr><td>⏚</td><td>Casing</td></tr>
</table></td></tr>
<tr><td>LMDHTA-W</td><td>Digital</td><td>Bare cable</td></tr>
<tr><td>LMDHTB</td><td>Digital</td><td>Connector</td><td rowspan="2">
</td><td rowspan="2">LMTB Series</td></tr>
<tr><td>LMDHTB-W</td><td>Digital</td><td>Bare cable</td></tr>
<tr><td>LMDHTC</td><td>Digital</td><td>Connector</td><td rowspan="2">
</td><td rowspan="2">LMTC Series</td><td rowspan="2">Example 2: Bare cable outlet mode and signal cable pin illustration

<table>
<tr><th colspan="2">Signal cable</th></tr>
<tr><td>Signal</td><td>Color</td></tr>
<tr><td>Vcc</td><td>Brown</td></tr>
<tr><td>Hall A(out)</td><td>White</td></tr>
<tr><td>Hall B(out)</td><td>Gray</td></tr>
<tr><td>Hall C(out)</td><td>Yellow</td></tr>
<tr><td>GND</td><td>Green</td></tr>
<tr><td>⏚</td><td>Isolation net</td></tr>
</table></td></tr>
<tr><td>LMDHTC-W</td><td>Digital</td><td>Bare cable</td></tr>
</table>

6.6.1 Hall sensor installation instructions

⚠ DANGER!

Attention to Hall sensor stroke!

- To evaluate the installation of the Hall sensor, it's necessary to confirm that the full stroke of the stator cannot be exceeded. If the stator is exceeded, an error alarm may occur in the drive control.

When a Hall sensor is fastened onto a forcer, the bottom surface of the Hall sensor needs to be coplanar with datum plane A or shall not exceed datum plane A.

Refer to S1 in Section 4.1.1 for the installation gap of LMSA/LMSA-Z series.
Refer to S2 in Section 4.1.2 for the installation gap of LMFA/LMFP series.
Refer to S3 in Section 4.1.2 for the installation gap of LMFA/LMFP precision water-cooling series.

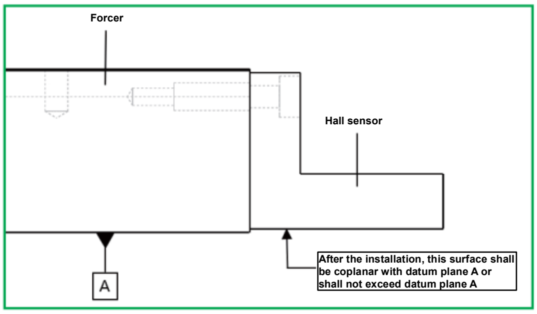


Figure6.6-1 Hall sensor installation illustration

6.6.2 Selection of Hall sensor screws

For Hall sensors of iron core linear motors, M3 screws shall be used. For hall sensors of ironless linear motors, there are variations according to the model number.

Table 6.6-6 Hall sensor screw selection chart

Screw specification	Applicable Hall sensor series
M2	LMAHEF3, LMAHEF3-W
M3	LMAHS, LMAHS-W, LMAHSA, LMAHSA-W LMAHF1, LMAHF1-W, LMAHF2, LMAHF2-W LMAHSA-D, LMAHSAA-D, LMAHFA1-D, LMAHFA2-D LMAHC, LMAHC-W, LMAHC2, LMAHC2-W LMAHC3, LMAHC3-W, LMAHCA-D, LMDHTA, LMDHTA-W
M4	LMDHTB, LMDHTB-W, LMDHTC, LMDHTC-W

6.7 Hall encoder

Analog Hall encoder is used on the linear motor positioning platform. Apart from the incremental linear scale and magnetic scale available in the market, it provides customers with an additional option of encoder for selection. It only requires the installation of a Hall sensor read head such that encoder position scale can be omitted, and it is able to achieve excellent positioning capability when operating with the existing stator parts of the linear motor.

Characteristics

- Use in conjunction with iron core linear motor.
- Replace linear scale, magnetic scale encoders.
- Easy for assembly.
- Suitable to applications with general precision requirements for point-to-point long stroke.
- Excellent dust-resistant, oil-resistant and water-resistant.

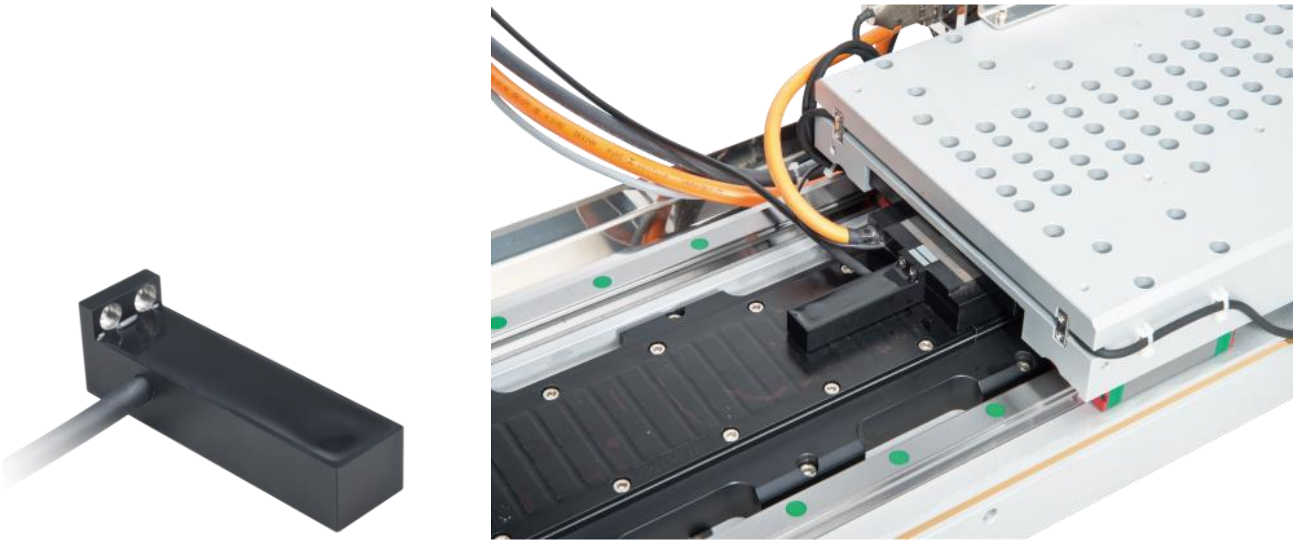
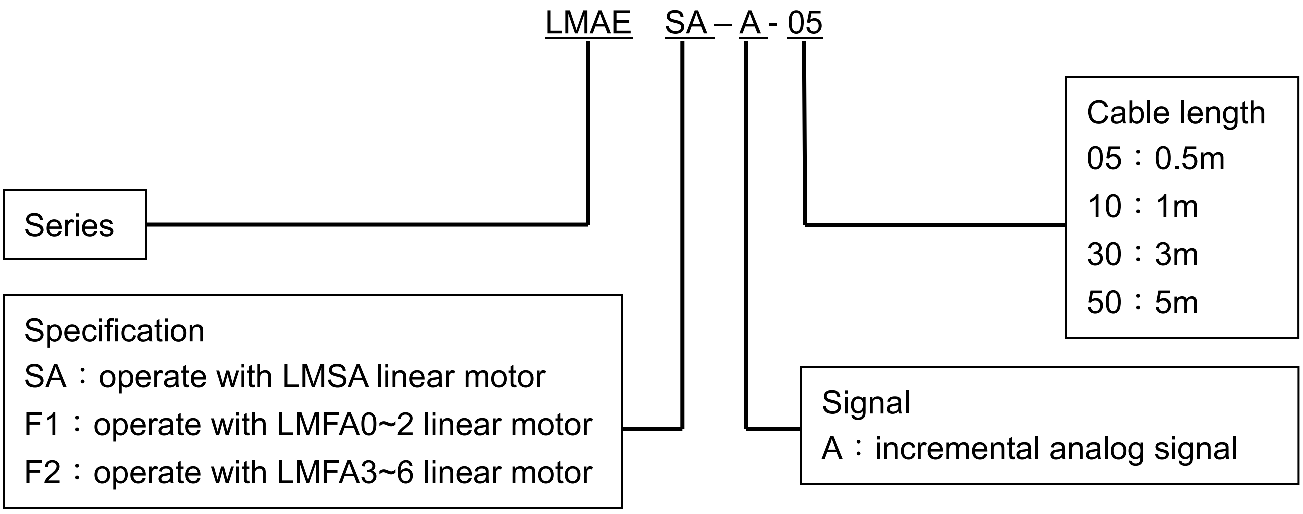


Figure 6.7-1 Actual images of Hall encoder

6.7.1 Hall encoder coding instructions

Product model number coding principle



signal pin illustration (refer to Table 6.7-1)

Table 6.7-1 Hall encoder signal pin chart

Function	Signal	Color
Power	+5V	Brown
	GND	White
Output signal	SIN+	Green
	SIN-	Yellow
	COS+	Blue
	COS-	Red

6.7.2 Hall encoder characteristic specification

Table 6.7-2 Hall encoder characteristic chart

	LMAESA	LMAEF1	LMAEF2
Power supply	5V±5%	5V±5%	5V±5%
Pole pair pitch	30mm	30mm	46mm
Resolution (1)	7.5μm	7.5μm	11.5μm
Repeatability (1)	±15μm	±15μm	±23μm
Accuracy (1)(2)	±45μm	±45μm	±69μm
Signal Output signal	SIN/COS 1Vp-p	SIN/COS 1Vp-p	SIN/COS 1Vp-p
Operating temperature (shall not freeze)	0℃~50℃	0℃~50℃	0℃~50℃
Storage temperature (shall not freeze)	-5℃~60℃	-5℃~60℃	-5℃~60℃

NOTE Operate with HIWIN driver, subdivision quantity of 4000.

NOTE Accuracy refers to the error after compensation (operate with HIWIN driver)

NOTE LMAESA can be shipped together with the SSA single-axis positioning platform, and the repeatability can reach ±5μm.

6.7.3 Hall encoder dimension

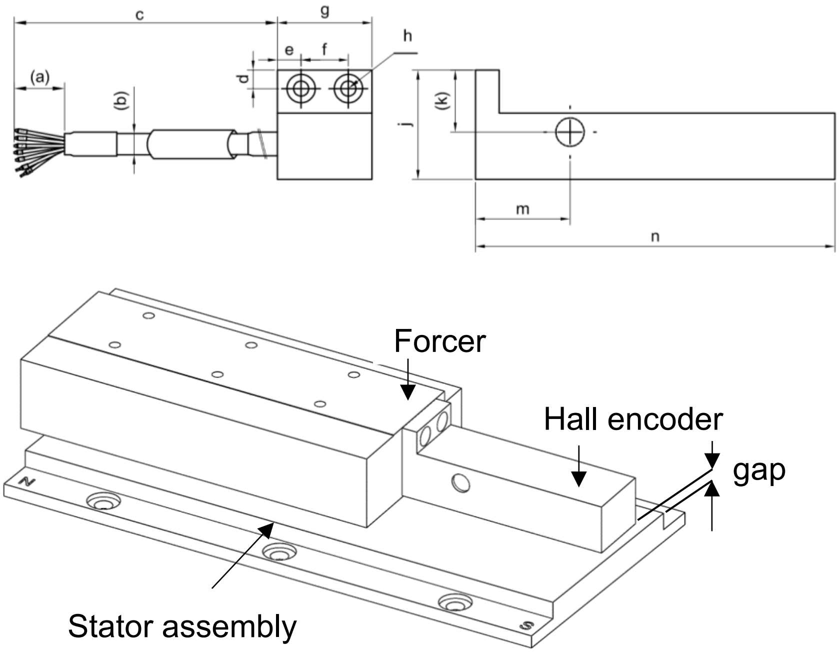


Figure 6.7-2 Hall encoder dimension illustration

Table 6.7-3 Hall encoder specification dimension chart

Dimension	LMAESA-A	LMAEF1-A	LMAEF2-A
a(mm)	50	50	50
b(mm)	5, Bending radius R=25	5, Bending radius R=25	5, Bending radius R=25
c(mm)	500~5000	500~5000	500~5000
d(mm)	3.9	4.4	4.4
e(mm)	5	5	5
f(mm)	10	10	10
g(mm)	20	20	20
h(mm)	2-Ø3.5 THRU, Ø6x3DP	2-Ø3.5 THRU, Ø6x3DP	2-Ø3.5 THRU, Ø6x3DP
j(mm)	23.1	26.6	26.6
k(mm)	13.1	16.6	15.6
m(mm)	24.3	24.3	24.3
n(mm)	72.3	72.3	98.5
gap(mm)	1.1	1.4(Cover type)/ 1.9(Epoxy type)	1.4(Cover type)/ 1.9(Epoxy type)

7. Troubleshooting

7.1 Troubleshooting

Table 7.1-1 Troubleshooting

Symptom	Cause	Action
Motor cannot rotate at all.	Wrong cable wiring	Check the cable connected to the controller.
Wrong rotating direction	Wrong encoder setting	Check encoder settings.
	Wrong motor power cable wiring	Interchange the two-phase power cable connected to the controller.
Smell of burning	Abnormal operation of cooling system	Check the cooling system.
	Wrong controller setting	Check controller settings.
	Wrong motor parameters setting	Check motor parameters setting.
Abnormal temperature of motor outer casing	Abnormal operation of cooling system	Check the cooling system.
	Wrong controller setting	Check controller settings.
	Abnormal operation	Check assembly method.
	Abnormal temperature control display	Check assembly method and grounding of shielding.
Unstable rotation (vibration)	Insulation failure	Check the resistance value of phase/earth is larger than 10MΩ.
	Wrong encoder installation	Check installation stiffness of encoder.
	Wrong encoder signal	Check encoder grounding and connection.
	Encoder signal interference	Check grounding of shielding.
	Wrong controller setting	Check controller settings.
Hard to rotate or abnormal friction noise	Abnormal installation of rotor	Check assembly method.
	Foreign objects exist in the air gap.	Remove foreign objects.
	Abnormal air gap	Check assembly tolerance and structural rigidity.

8. Waste Disposal

8.1 Waste Disposal

⚠ DANGER!

Danger from strong magnet!

Permanent magnetic materials must be fully demagnetized before subsequent treatment is performed. Otherwise, it may cause serious damage.

- As or the demagnetization of permanent magnetic materials are put in the furnace in a solid, heat-resistant container made of non-magnetic material, the heat must be at least 300°C during a holding time of at least 30 minutes.

ATTENTION!

Danger caused by environmentally hazardous substances!

The danger to the environment depends on the type of substance used.

- Waste disposal must follow the local relevant regulations and the recycling procedure of recyclable materials.
- Waste materials include electronic materials, iron, aluminum, insulating materials, permanent magnetic materials, etc. Please follow the relevant procedures for recycling.
- If the packaging materials used in the product are recyclable, they must be recycled.

When products relevant to linear motor reach usage expiration, they need to be treated properly before disposal, especially the permanent magnetic materials. If they are not demagnetized according to the warning aforementioned, they might cause severe injury to workers.

HIWIN is not responsible for any damages, accidents, or injuries caused by failure to follow the above precautions.

9. Appendix

9.1 Screw selection rules and instructions

- Before installing forcer and stator parts, please check the installation dimension first
- Clean the forcer and stator parts installation surfaces and machine surfaces
- For screws, please use screws comply with the DIN912 standard and strength of 10.9.
- Please use new screws and prevent repetitively remove and install forcer and stator as much as possible
- Please select appropriate screws according to the screw hole/threaded hole dimensions of forcer and stator
- During the installation of the stator, the screw head shall not exceed the stator surface
- During the fastening of screws, please use torque wrench, and refer to the recommended fastening torque values indicated in the following table
- In moving and vibrating structures, must be fastening of screws with screw glue.

9.1.1 Force and stator screw installation hole specification table

Table 9.1-1 LMFA forcer, stator screw installation hole specification table

LMFA series forcer		LMFA series stator	
LMFA0□(L)~LMFA2□(L)	M5x0.8Px10DP	LMF0S□(E)	Ø4.5THRU; Ø8x2DP
		LMF1S□(E)	Ø5.5THRU; Ø10x1.5DP
LMFA0□(L)~LMFA2□(L)-P LMFP24	M5x0.8Px9DP	LMF2S□(E)	Ø5.5THRU; Ø10x3.5DP
LMFA3□(L)~LMFA6□(L)	M8x1.25Px14DP	LMF3S□(E)	Ø9THRU; Ø15x6DP
		LMF4S□(E)	Ø9THRU; Ø15x6DP
LMFA3□(L)~LMFA6□(L)-P LMFP3□~6□	M8x1.25Px12.5DP	LMF5S□E	Ø9THRU; Ø15x6DP
		LMF6S□E	Ø6.5THRU; Ø10.5x6DP

Table 9.1-2 LMSA forcer, stator screw installation hole specification table

LMSA series forcer		LMSA series stator		
LMSA□□(L) LMSA□□-Z	M4x0.7Px4DP		Cover type	Epoxy type
		LMSA1S□(EA)	Ø4.5 THRU	Ø4.5 THRU, Ø8x5.7DP
		LMSA2S□(EA)	Ø5.5 THRU	Ø5.5 THRU, Ø10x5.7DP
		LMSA3S□(EA)	Ø5.5 THRU	Ø5.5 THRU, Ø10x5.7DP
		LMSACS□(EA)	Ø5.5 THRU	Ø5.5 THRU, Ø10x5.7DP

Table 9.1-3 LMSS forcer, stator screw installation hole specification table

LMSS series forcer		LMSS series stator	
LMSS11	M3x0.5Px5DP	LMSS1S□	Ø4.5 THRU

Table 9.1-4 LMSC forcer, stator screw installation hole specification table

LMSC series forcer		LMSC series stator	
LMSC7(L)	M8x1.25Px12DP	LMS3S□	Ø6.5 THRU, Ø11x4DP

Table 9.1-5 LMC forcer, stator screw installation hole specification table

LMC series forcer			LMC series stator	
	Bottom installation hole	Side installation hole		
LMCA	M3x0.5Px4.5DP	M4x0.7Px5DP	LMCAS□	Ø5.5 THRU, Ø9.5x8DP
LMCB			LMCBS□	Ø5.5 THRU, Ø9.5x8DP
LMCC			LMCCS□	Ø6.5 THRU, Ø11x10DP
LMCD	M5x0.8Px6DP	M4x0.7Px8DP	LMCDS□	Ø6.5 THRU, Ø11x8DP
LMCE			LMCES□	Ø6.5 THRU, Ø11x8DP
LMCF		M5x0.8Px9DP	LMCFS□	Ø6.5 THRU, Ø11x8DP

Table 9.1-6 LMC-EF forcer, stator screw installation hole specification table

LMC-EF series forcer		LMC-EF series stator	
	Bottom installation hole		
LMC-EFC	M4x0.7Px5DP M4x0.7Px12DP	LMC-EFCS□	Ø4.2 THRU, Ø7.5x6.35DP
LMC-EFE	M4x0.7Px5DP M4x0.7Px12DP	LMC-EFES□	Ø5.5 THRU, Ø9.5x6.85DP
LMC-EFF	M5x0.8Px10DP M5x0.8Px12DP	LMC-EFFS□	Ø5.5 THRU, Ø9.5x8DP

Table 9.1-7 LMC-HUB forcer, stator screw installation hole specification table

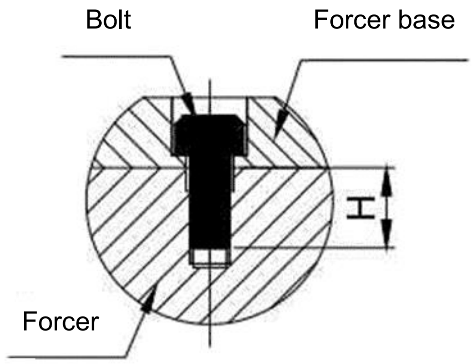
LMC-HUB series forcer			LMC-HUB series stator	
	Bottom installation hole	Side installation hole		
LMC-HUB	M3x0.5P THRU	M3x0.5Px3DP	LMC-HUBS□	Ø4.5 THRU, Ø8x4.5DP

Table 9.1-8 LMT forcer screw installation hole specification table

LMT series forcer	
LMT2	M3x0.5Px5DP
LMT6	M3x0.5Px5DP
LMTA	M4x0.7Px6DP
LMTB	M6x1.0Px9DP
LMTC	M8x1.25Px12DP

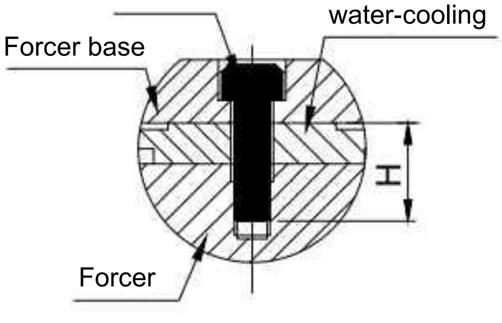
9.1.2 Forcer recommended screw fastening depth table

Table 9.1-9 Forcer screw fastening depth table

Forcer specification	Screw specification	Screw fastening depth H(mm)	Schematic illustration
LMSS	M3	4.5 0/-1	
LMSA/LMSA-Z	M4	3.5 0/-1	
LMFA0□~2□	M5	9 0/-2.5	
LMFA0□~2□-P	M5	8 0/-2	
LMFP24	M5	8 0/-2	
LMFA3□~6□	M8	12 0/-3.5	
LMFA3□~6□-P	M8	11 0/-3	
LMFP3□~6□	M8	11 0/-3	
LMSC7	M8	11 0/-3	
LMCA~C	M3(bottom) M4(side)	4 0/-1	
LMCD~E	M5(bottom) M4(side)	5 0/-1 6 0/-2	
LMCF	M5(bottom) M5(side)	5 0/-1 8 0/-2	
LMC-EFC/EFE	M4	4 0/-1 8 0/-3	
LMC-EFF	M5	8 0/-2s	
LMT2□ LMT6□	M3	4.5 0/-1	
LMTA□	M4	5 0/-1	
LMTB□	M6	8 0/-2	
LMTC□	M8	11 0/-3	

NOTE LMC-EFC series forcer bottom threaded holes have two types of depths, please refer to the catalog drawings.

Table 9.1-10 Screw fastening depth table for forcer equipped with precision water-cooling

Forcer specification	Screw specification	Screw fastening depth H(mm)	Schematic illustration
LMFA3□~6□	M8	24 0/-3.5	
LMFA3□~6□-P	M8	23 0/-3	
LMFP3□~6□	M8	23 0/-3	

9.1.3 Stator recommended screw fastening minimum depth table

Table 9.1-11 Stator screw fastening depth table

Material	Carbon steel	Cast iron	Aluminum alloy
Fastening depth	1.2 x d	1.6 x d	1.8 x d

NOTE The maximum fastening depth is determined based on the threaded hole on the customer's machine.

9.1.4 Forcer and stator recommended screw torque table

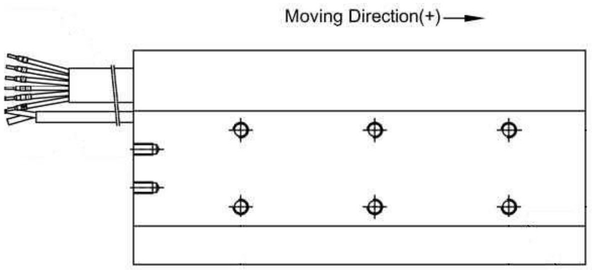
Table 9.1-12 Screw torque specification table

Screw dimension	Torque (kgf-cm)	Torque (N-m)
M3x0.5P	15	1.5
M4x0.7P	34	3.3
M5x0.8P	69	6.8
M6x1.0P	118	11.6
M8x1.25P	286	28.1

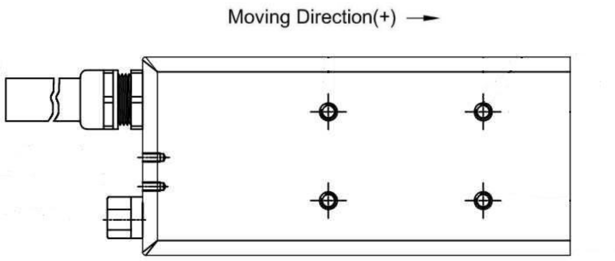
9.2 Moving direction of Linear motor

Iron core:

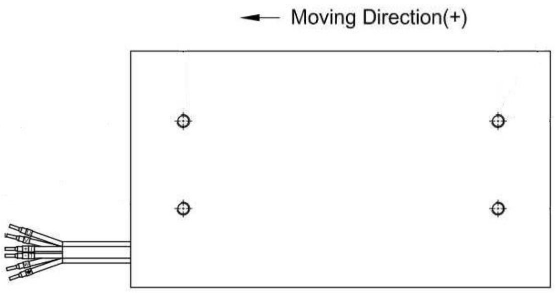
LMSA series



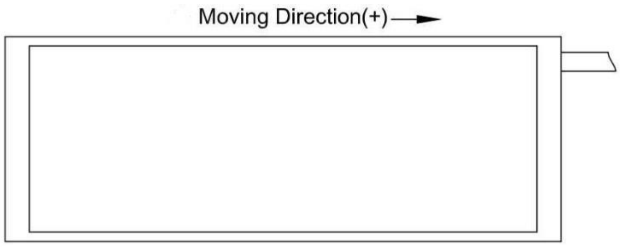
LMFA series



LMSS series

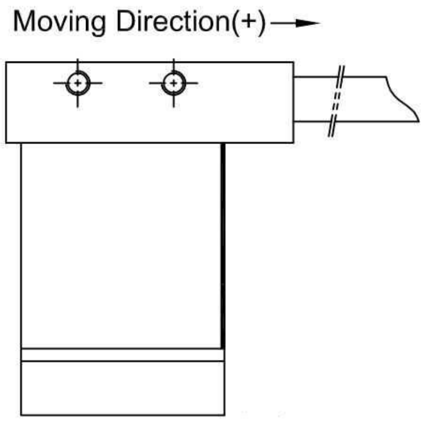


LMSC series

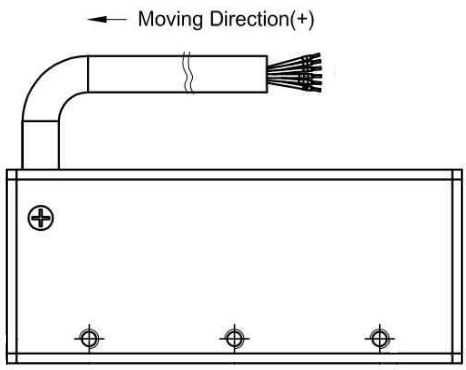


Ironless:

LMC series



LMT series



9.3 Introduction of Specific Terms

Continuous force F_c [N]
It is defined as the output thrust force of the motor running continuously without stopping under the environmental temperature of 25℃, and such Continuous force corresponds to the continuous current applied to the motorI_c.

Continuous current I_c $[A_{rms}]$
It is defined as the current that can be supplied to the motor coil continuously under the environmental temperature of 25℃, and it also generates the current for the Continuous force.

Water-cooling Continuous force (F_c(wc) [N]
It is defined as the output thrust force of the motor running continuously without stopping under the water-cooling temperature of 20℃, and such water-cooling Continuous force corresponds to the Continuous current(wc) applied to the motorI_c.

Continuous current(wc) I_c(wc) $[A_{rms}]$
It is defined as the current that can be supplied to the motor coil continuously under the water-cooling temperature of 20℃, and it also generates the current for the water-cooling Continuous force.

Peak force F_p [N]
It is defined as the maximum thrust force that can be outputted by the motor within the time not exceeding one second. It is generally used for the purpose of acceleration and deceleration.

Peak current I_p $[A_{rms}]$
It is defined as the instant large current corresponding to the peak thrust achieved by the motor, and for the normal scope of operation, the peak current is permitted for one second.
Ultimate force F_u [N]
It is defined as the output thrust force corresponding to the Ultimate current I_u of the motor.

Ultimate force F_u [N]
It is defined as the output thrust force corresponding to the Ultimate current I_u of the motor.

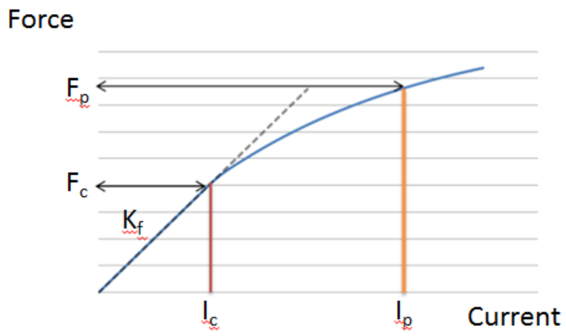
Ultimate current I_u $[A_{rms}]$
It is defined as five times of the continuous current I_c of the motor; under such current, the thrust force outputted by the motor is within the saturated non-linear zone, and the Force constant decreases. Input of such current can cause over-temperature risk of the motor, and the operating time is recommended to be less than 0.5 second.

Attraction force F_a [N]
It is defined as the acting force between the forcer and stator of an iron core linear motor under the rated air gap, and the preload applied by such force on the sliding block is borne by the sliding track.

Maximum winding temperature T_{max} [℃]
It is defined as the acceptable maximum temperature of the motor coil. The actual equilibrium temperature of the motor depends on the factors of the mechanism, cooling method and the movement planning etc. There may be some deviation from the theoretical calculation, and the result of actual measurement is typically used.

Electrical time constant K_e [ms]
It is defined as the time required for the current supplied to the motor to reach 63% of the target value, and when such value is smaller, it means that the response time is faster.

Force constant K_f $[N/A_{rms}]$
It is defined as the output thrust force of the motor under the unit current, and except for the LMFA water-cooling motor series, when the rest of the series are under the normal operating scope, the output thrust force and the input current approach the linear relationship, and the non-linear portion is affected by the iron core saturation.



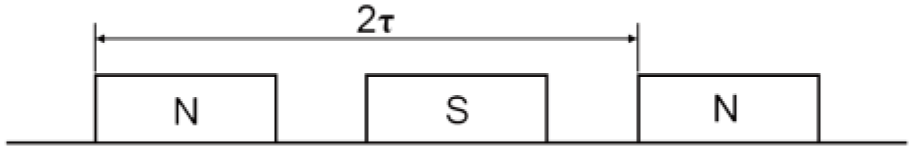
Resistance R_{25} [Ω]
It is defined as the line-to-line resistance of the motor measured when the coil temperature is 25℃; the resistance increases along with the increase of the temperature.

$$R_c = R_{25} \times (1 + 0.00393) \times (T_c - 25)$$

R_c: refers to the line-to-line resistance under any temperature
T_c: any temperature

Inductance L [mH]
It is defined as the line-to-line inductance (excluding stator) of the motor measured.

Pole pair pitch 2τ [mm]
It is defined as the distance between two magenta of the same polarity on the stator, i.e. N→N or S→S.

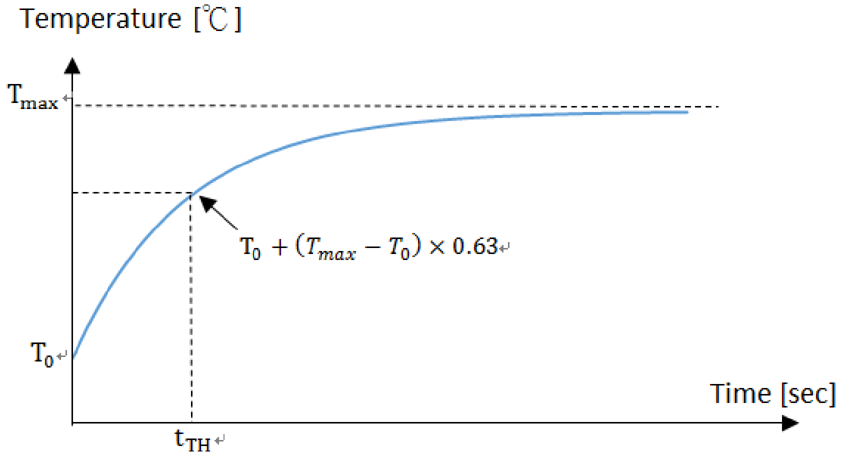


Back EMF constant K_v $[V_{rms}/(m/s)]$
It is defined as the induced EMF generated by the unit speed of the motor when the magnet temperature is 25℃. It occurs when the coil senses a magnetic field change, and the EMF generated to resist the current passing through.

Motor constant K_m $[\mathrm{N}/\sqrt{W}]$
It is defined as the ratio of the motor output thrust force to the square root of the power consumption when the coil and magnet temperatures are 25℃. As the motor constant is higher, it means that when the motor outputs a specific thrust force, there is a lower power loss, and such constant is used as one of the indicators for determining the motor efficiency.

Thermal resistance R_{TH} $[°\mathrm{C}/W]$
It is defined as the thermal resistance from the internal of the motor coil to the heat dissipating environment. As the thermal resistance is smaller, it means that under the same amount of heat input, the temperature difference between the coil and the heat dissipating environment is smaller, i.e. the heat dissipating effect is better.

Thermal time constant t_{TH} [sec]
It is defined as the time required for the coil initial temperature to T_0 rise to 63% of the Maximum winding temperature T_{max} when the motor is supplied with the continuous current.



Minimum flow rate (L/min)
It is defined as the minimum flow rate of the coolant required for the motor to reach the water-cooling Continuous force under the rated Temperature of cooling water $F_c(wc)$.

Temperature of cooling water [℃]
It is defined as the temperature required to be reached by the motor coolant under the minimum flow rate in order to achieve the water-cooling Continuous force $F_c(wc)$.

Pressure drop $\Delta\mathrm{P}$ [bar]
It is defined as the pressure difference between the inlet and outlet when the coolant is under the minimum flow rate.

Peak force maximum speed V_{max,F_p} [m/s]
It is defined as the maximum speed that can be achieved by the motor under the Peak force; this parameter depends on the Maximum DC bus voltage.

Maximum electric power input $P_{EL,max,}$ [W]
It is defined as the required input power under the condition where the motor is operating at the Peak force with maximum speed V_{max,F_p} and Maximum dissipated heat output $Q_{P,H,max}$.

Maximum dissipated heat output $Q_{P,H,max}$ [W]
It is defined as the heat generated by the coil of the motor when the coil is at the maximum temperature T_{max}.

Stall current I_0 $[A_{rms}]$
It is defined as the current upper limit that can be supplied under the condition where the motor is under the environmental temperature of 25℃ and the locked-rotor condition, and such value is related to the criteria of heat dissipation.

Stall force F_0 [N]
It is defined as the thrust force upper limit that can be provided when the motor is under the short stroke (stroke smaller than the pole pair pitch 2τ) and the locked-rotor application, and such value is limited by the Stall current.

Maximum DC bus voltage $[V_{DC}]$
It is defined as the Maximum DC bus voltage that can be used by the motor under the normal working environment.