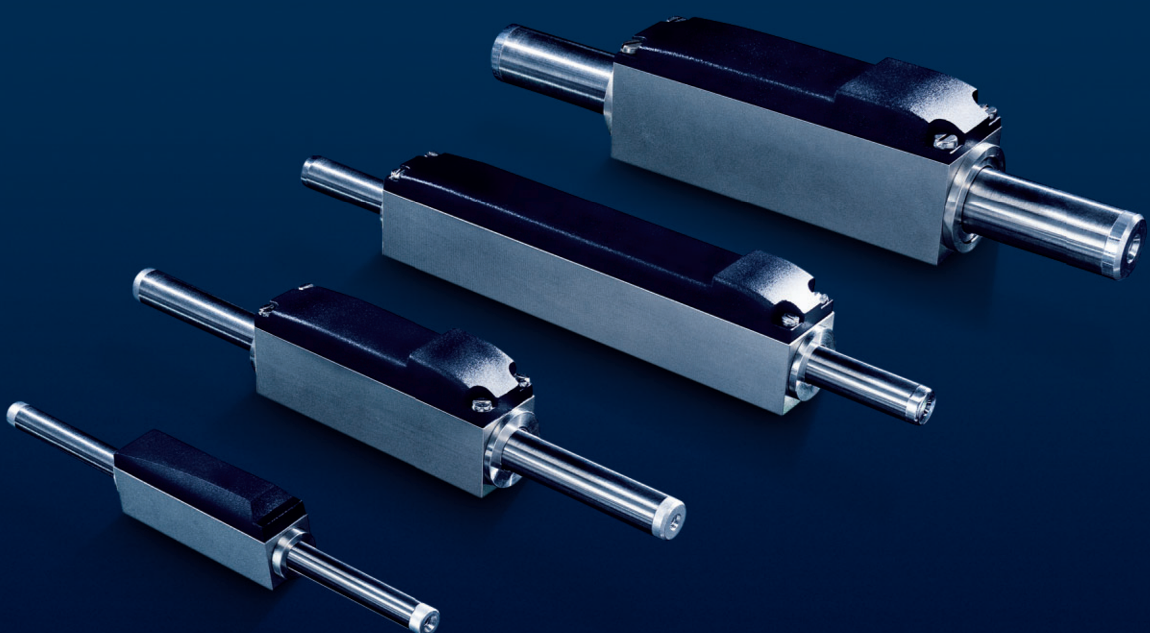
FAUHLABER

Linear DC-Servomotors
Technical Information



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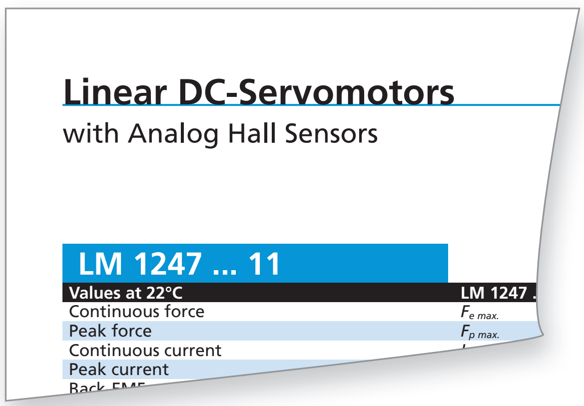
Linear DC-Servomotors

Technical Information



Linear DC-Servomotors
with Analog Hall Sensors

LM 1247 ... 11

Values at 22°C	LM 1247 ...
Continuous force	$F_{e\ max.}$
Peak force	$F_{p\ max.}$
Continuous current	
Peak current	
Back-EMF	

Notes on technical datasheet

All values at 22 °C.

Continuous force $F_{e\ max.}$ [N]
The maximum force delivered by the motor at the thermal limit in continuous duty operation and with a reduced thermal resistance R_{th2} by 55%.

$$F_{e\ max.} = k_F \cdot I_{e\ max.}$$

Peak force $F_{p\ max.}$ [N]
The maximum force delivered by the motor at the thermal limit in intermittent duty operation (max. 1 s, 10% duty cycle) and with a reduced thermal resistance R_{th2} by 55%.

$$F_{p\ max.} = k_F \cdot I_{p\ max.}$$

Continuous current $I_{e\ max.}$ [A]
The maximum motor current consumption at the thermal limit in continuous duty operation and with a reduced thermal resistance R_{th2} by 55%.

$$I_{e\ max.} = \sqrt{\frac{T_{125} - T_{22}}{R \cdot (1 + \alpha_{22} \cdot (T_{125} - T_{22})) \cdot (R_{th\ 1} + 0{,}45 \cdot R_{th\ 2})}} \cdot \frac{\sqrt{2}}{\sqrt{3}}$$

Peak current $I_{p\ max.}$ [A]
The maximum motor current consumption at the thermal limit in intermittent duty operation (max. 1 s, 10% duty cycle) and with a reduced thermal resistance R_{th2} by 55%.

Back-EMF constant k_E [V/m/s]
The constant corresponding to the relationship between the induced voltage in the motor phases and the linear motion speed.

$$k_E = \frac{2 \cdot k_F}{\sqrt{6}}$$

Force constant k_F [N/A]
The constant corresponding to the relationship between the motor force delivered and the motor line current with sine wave commutation.

Terminal resistance, phase-phase R [Ω] ±12%
The resistance measured between two motor phases. This value is directly influenced by the coil temperature (temperature coefficient: $\alpha_{22} = 0{,}0038\ K^{-1}$).

Terminal inductance, phase-phase L [µH]
The inductance measured between two phases at 1 kHz.

Stroke length $s_{max.}$ [mm]
The datasheet parameters are only valid if the rod movement is within the given stroke range, $s_{max.}$. Aligning the rod and stator axial centres, the allowed movement is therefore half the overall stroke length.

Repeatability σ_r [µm]
The typical measured difference when repeating several times the same movement under the same conditions. Measurements done with FDS MC (-01, 11 versions) and 3rd party sin/cos motion controller (-02, 12 versions).

Accuracy σ_a [µm]
The typical positioning error. This value corresponds to the difference between the set position and the exact measured position of the system. Measurements done with FDS MC (-01, 11 versions) and 3rd party sin/cos motion controller (-02, 12 versions).

Acceleration $a_{e\ max.}$ [m/s²]
The maximum theoretical no-load acceleration from standstill in continuous duty operation.

$$a_{e\ max.} = \frac{F_{e\ max.}}{m_m}$$

Speed $v_{e\ max.}$ [m/s]
The maximum theoretical no-load speed from standstill, considering a triangular speed profile and maximum stroke length.

$$v_{e\ max.} = \sqrt{a_{e\ max.} \cdot s_{max.}}$$

Thermal resistance $R_{th\ 1}$; $R_{th\ 2}$ [K/W]
R_{th1} corresponds to the value between coil and housing.
R_{th2} corresponds to the value between housing and ambient air.
The listed values refer to a motor totally surrounded by air. R_{th2} can be reduced with a heat sink and/or forced air cooling.

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Thermal time constant τ_{w1}; τ_{w2} [s]
The thermal time constant of the coil (τ_{w1}) and housing (τ_{w2}), respectively.

Operating temperature range [°C]
The minimum and maximum permissible operating temperature values of the motors.

Rod mass m_m [g]
The normal mass of the rod (cylinder with magnets).

Total mass m_t [g]
The total mass of the linear DC-Servomotor.

Magnetic pitch τ_m [mm]
The distance between two equal poles.

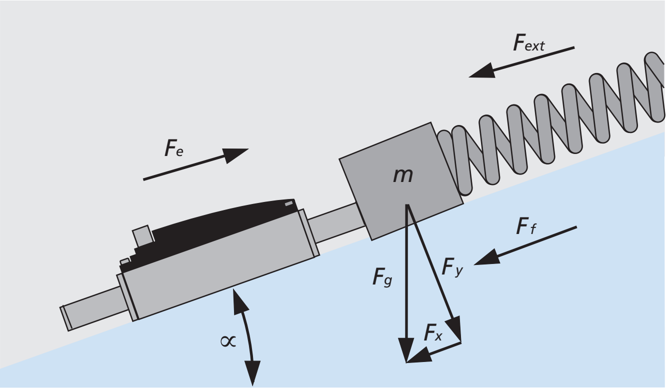
Rod bearings
The material and type of bearings.

Housing material
The material of the motor housing.

Direction of movement
The direction of movement is reversible, determined by the control electronics.

Force calculation

To move a mass on a slope, the motor needs to deliver a force to accelerate the load and overcome all forces opposing the movement.



The sum of forces shown in above figure has to be equal to:

$$\sum F = m \cdot a \qquad [N]$$

Entering the various forces in this equation it follows that:

$$F_e - F_{ext} - F_f - F_x = m \cdot a \qquad [N]$$

where:

F_e :	Continuous force delivered by motor	[N]
F_{ext} :	External force	[N]
F_f :	Friction force $F_f = m \cdot g \cdot \mu \cdot \cos(\propto)$	[N]
F_x :	Parallel force $F_x = m \cdot g \cdot \sin(\propto)$	[N]
m :	Total mass (incl. rod)	[kg]
g :	Gravity acceleration	[m/s²]
a :	Acceleration	[m/s²]

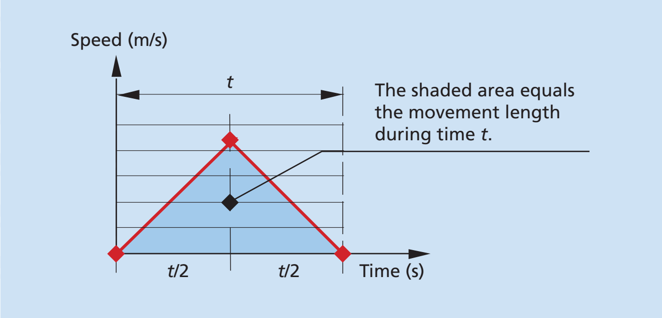
Speed profiles

Shifting any load from point A to point B is subject to the laws of kinematics.

Equations of a uniform straight-line movement and uniformly accelerated movement allow definition of the various speed vs. time profiles.

Prior to calculating the continuous duty force delivered by the motor, a speed profile representing the various load movements needs to be defined.

Triangular speed profile
The triangular speed profile simply consists of an acceleration and a deceleration time.



Displacement: $$s = \frac{1}{2} \cdot v \cdot t = \frac{1}{4} \cdot a \cdot t^2 = \frac{v^2}{a} \qquad [m]$$

Speed: $$v = 2 \cdot \frac{s}{t} = \frac{a \cdot t}{2} = \sqrt{a \cdot s} \qquad [m/s]$$

Acceleration: $$a = 4 \cdot \frac{s}{t^2} = 2 \cdot \frac{v}{t} = \frac{v^2}{s} \qquad [m/s^2]$$

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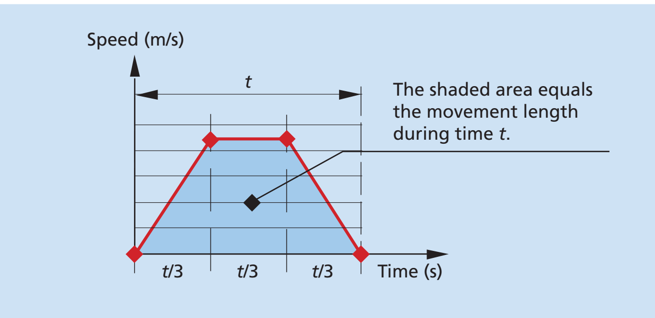
Trapezoidal speed profile

The trapezoidal speed profile, acceleration, speed and deceleration, allow simple calculation and represent typical real application cases.



Displacement:	$s = \frac{2}{3} \cdot v \cdot t = \frac{1}{4{,}5} \cdot a \cdot t^2 = 2 \cdot \frac{v^2}{a}$	[m]
Speed:	$v = 1{,}5 \cdot \frac{s}{t} = \frac{a \cdot t}{3} = \sqrt{\frac{a \cdot s}{2}}$	[m/s]
Acceleration:	$a = 4{,}5 \cdot \frac{s}{t^2} = 3 \cdot \frac{v}{t} = 2 \cdot \frac{v^2}{s}$	[m/s²]

How to select a linear DC-Servomotor

This section describes a step-by-step procedure to select a linear DC-Servomotor.

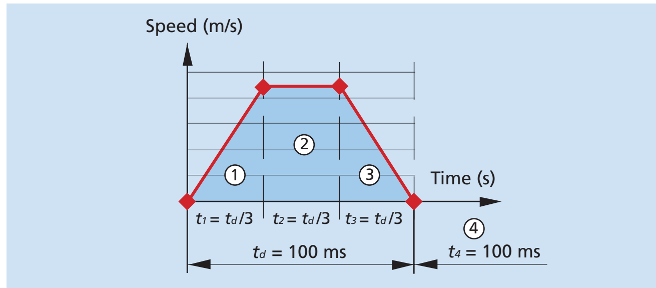
Speed profile definition

To start, it is necessary to define the speed profile of the load movements.

Movement characteristics are the first issues to be considered. Which is the maximum speed? How fast should the mass be accelerated? Which is the length of movement the mass needs to achieve? How long is the rest time?

Should the movement parameters not be clearly defined, it is recommended to use a triangular or trapezoidal profile.

Let’s assume a total mass of 500 g that needs to be moved 20 mm in 100 ms on a slope having a rising angle of 20° considering a trapezoidal speed profile.



	Unit	①	②	③	④
s (displacement)	m	0,005	0,01	0,005	0
v (speed)	m/s	0 ... 0,3	0,3	0,3 ... 0	0
a (acceleration)	m/s²	9,0	0	–9,0	0
t (time)	s	0,033	0,033	0,033	0,100

Calculation example

Speed and acceleration of part ①

$$v_{max.} = 1{,}5 \cdot \frac{s}{t} = 1{,}5 \cdot \frac{20 \cdot 10^{-3}}{100 \cdot 10^{-3}} = 0{,}3 \text{ m/s}$$

$$a = 4{,}5 \cdot \frac{s}{t^2} = 4{,}5 \cdot \frac{20 \cdot 10^{-3}}{(100 \cdot 10^{-3})^2} = 9 \text{ m/s}^2$$

Force definition

Assuming a total mass of 500 g and a friction coefficient of 0,2, the following forces result:

			Forward				Backward			
Force	Unit	Symbol	①	②	③	④	①	②	③	④
Friction	N	F_f	0,94	0,94	0,94	-0,94	0,94	0,94	0,94	0,94
Parallel	N	F_x	1,71	1,71	1,71	1,71	-1,71	-1,71	-1,71	-1,71
Acceleration	N	F_a	4,5	0	-4,5	0	4,5	0	-4,5	0
Total	N	F_t	7,15	2,65	-1,85	0,77	3,73	-0,77	-5,27	-0,77

Calculation example

Friction and acceleration forces of part ①

$$F_f = m \cdot g \cdot \mu \cdot \cos(\alpha) = 0{,}5 \cdot 10 \cdot 0{,}2 \cdot \cos(20°) = 0{,}94 \text{ N}$$

$$F_a = m \cdot a = 0{,}5 \cdot 9 = 4{,}5 \text{ N}$$

Motor selection

Now that the forces of the three parts of the profile are known, requested peak and continuous forces can be calculated in function of the time of each part.

The peak force is the highest one achieved during the motion cycle.

$$F_p = \max.(|\mathbf{7{,}15}|, |2{,}65|, |-1{,}85|, |0{,}77|, |3{,}73|, |-0{,}77|, |-5{,}27|, |-0{,}77|) = 7{,}15 \text{ N}$$

The continuous force is represented by the expression:

$$F_e = \sqrt{\frac{\Sigma\,(t \cdot F_t^2)}{2 \cdot \Sigma\, t}} = \ldots$$

$$F_e = \sqrt{\frac{0{,}033 \cdot 7{,}15^2 + 0{,}033 \cdot 2{,}65^2 + 0{,}033 \cdot (-1{,}85)^2 + 0{,}1 \cdot 0{,}77^2 + 0{,}033 \cdot 3{,}73^2 + 0{,}033 \cdot (-0{,}77)^2 + 0{,}033 \cdot (-5{,}27)^2 + 0{,}1 \cdot (-0{,}77)^2}{2 \cdot (0{,}033 + 0{,}033 + 0{,}033 + 0{,}1)}} = 2{,}98\ \text{N}$$

With these two values it is now possible to select the suitable motor for the application.

Linear DC-Servomotor **LM 1247–020–11**

$s_{max.} = 20$ mm ; $F_{e\,max.} = 3{,}6$ N ; $F_{p\,max.} = 10{,}7$ N

Coil winding temperature calculation

To obtain the coil winding temperature, the continuous motor current needs to be calculated.
For this example, considering a force constant k_F equal to 6,43 N/A, gives the result:

$$I_e = \frac{F_e}{k_f} = \frac{2{,}98}{6{,}43} = 0{,}46\ \text{A}$$

With an electrical resistance of 13,17 Ω, a total thermal resistance of 23,2 °C/W ($R_{th1} + R_{th2}$) and a reduced thermal resistance R_{th2} by 55% ($0{,}45 \cdot R_{th2}$), the resulting coil temperature is:

$$T_c\,(I) = \frac{R \cdot (R_{th1} + 0{,}45 \cdot R_{th2}) \cdot (I_e \cdot \frac{\sqrt{3}}{\sqrt{2}})^2 \cdot (1 - \alpha_{22} \cdot T_{22}) + T_{22}}{1 - \alpha_{22} \cdot R \cdot (R_{th1} + 0{,}45 \cdot R_{th2}) \cdot (I_e \cdot \frac{\sqrt{3}}{\sqrt{2}})^2} = \ldots$$

$$T_c\,(I) = \frac{13{,}17 \cdot (3{,}2 + 0{,}45 \cdot 20{,}0) \cdot (0{,}46 \cdot \frac{\sqrt{3}}{\sqrt{2}})^2 \cdot (1 - 0{,}0038 \cdot 22) + 22}{1 - 0{,}0038 \cdot 13{,}17\,(3{,}2 + 0{,}45 \cdot 20{,}0) \cdot (0{,}46 \cdot \frac{\sqrt{3}}{\sqrt{2}})^2} = 85{,}26\ °\text{C}$$

Linear DC-Servomotors

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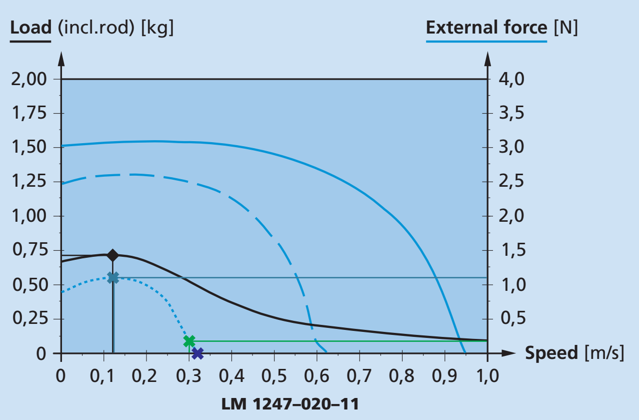
Motor characteristic curves

Motion profile:
Trapezoidal (*t1* = *t2* = *t3*), back and forth

Motor characteristic curves of the linear DC-Servomotor with the following parameters:

Displacement distance:	20 mm
Friction coefficient:	0,2
Slope angle:	20°
Rest time:	0,1 s



Load curve

Allows knowing the maximum applicable load (incl. rod) for a given speed with 0 N external force.

The graph shows that a maximum load (incl. rod) (◆) of 0,72 kg can be applied at a speed of 0,125 m/s.

External force curve

Allows knowing the maximum applicable external force for a given speed with a load of

- 0,1 kg
- 0,2 kg
- 0,5 kg

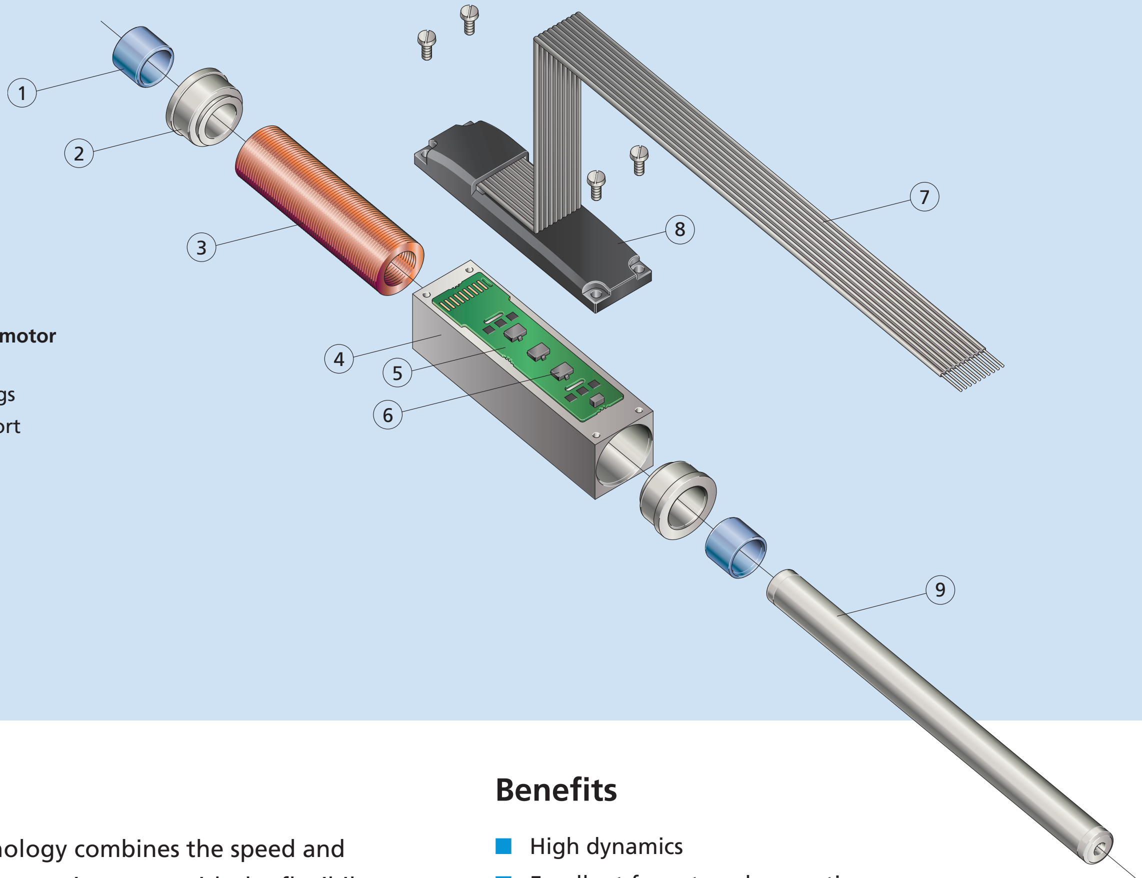
Considering the 0,5kg curve, the graph shows that the max. achievable speed without external forces, but with a load of 0,5 kg is 0,32 m/s (✖).

The maximum applicable external force (✖) at a speed of 0,3 m/s is 0,17 N.

The external peak force (✖) is achieved at a speed of 0,125 m/s, corresponding to a maximum applicable external force of 1,1 N.

The motor characteristic curves are dependent on movement parameters (speed profile, displacement distance, friction coefficient, slope angle and rest time). Consequently by modifying one or more of these input data, the motor characteristic curves will change accordingly. Comparing the above diagram with the one reported in the datasheet of the LM 1247-020-11 it can immediately be seen that with the same linear motor we get different curves by only changing the slope angle (in this example 20° and in the datasheet 0°).

Linear DC-Servomotors



Linear DC-Servomotor

① Sleeve bearings
② Bearing support
③ Coil
④ Housing
⑤ PCB
⑥ Hall sensors
⑦ Cable
⑧ Cover
⑨ Forcer rod

Features

FAULHABER technology combines the speed and robustness of a pneumatic system with the flexibility and reliability features of an electro-mechanical linear motor. The innovative design with a 3-phase self-supporting coil and non-magnetic metal housing offers outstanding performance.

The absence of residual static force and the excellent relationship between the linear force and current make these motors ideal for use in micro-positioning applications. Position control of the Linear DC-Servomotor is made possible by the built-in Hall sensors.

Performance lifetime of the Linear DC-Servomotors is mainly influenced by the wear of the sleeve bearings, which depends on operating speed and applied load of the cylinder rod.

Benefits

- High dynamics
- Excellent force to volume ratio
- No residual force present
- Non-magnetic metal housing
- Compact and robust construction
- No lubrication required
- Simple installation and configuration

Product code

LM1247–020–11

LM	Linear Motor
12	Motor width ☐ [mm]
47	Motor length [mm]
020	Stroke length [mm]
11	Sensors type: linear

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