Linear Motors

Series L7

Technical Product Information

We pioneer motion

SCHAEFFLER

Contents

Foreword

At its Suhl location in Thuringia, Schaeffler Industrial Drives, with around 140 employees, develops and manufactures highly advanced direct drives for industrial applications.

Over many years, we have developed our linear motor series to create optimised products that reach the boundaries of physical and economic feasibility. In addition to complex mechanical and thermal motor simulations, the design of the magnetic and cooling circuits, as well as magnet simulation, are our tools for optimisation and further development. Each of our linear motor series features a specific combination of outstanding properties, such as high force density, high velocity, excellent synchronous running, optimised power loss, and more, enabling us to cover virtually all applications in the field of linear direct drives.

Our linear motors are distinguished by their exceptional energy efficiency. Thanks to the optimised design and effective cooling of the motors, power loss is minimised and heat generation is significantly reduced. This not only leads to lower electricity costs and a reduced CO_2 footprint, but also to greater accuracy and a longer service life for the drive systems. Less heat means less thermal expansion and therefore more precise motion sequences. In addition, the service life of the components is significantly increased due to the lower thermal load, resulting in more sustainable and cost-efficient use. If a suitable motor cannot be found from our extensive selection, we will develop a customised high-end positioning and drive system to meet your requirements. Unlike any other company in the market, Schaeffler Industrial Drives is able to determine the optimum motor topology in line with your specifications and develop a drive to exceptionally high standards. Due to the close reciprocal relationship between a linear motor and its guidance system, you will benefit in particular from our expertise in monorail guidance systems. Not least for this reason, we also offer guidance system and rolling bearing arrangements for our linear motors that are tailored to the respective machine type.

This catalogue provides you with detailed information on our L7 linear motors, their characteristics and their possible applications. Customers place their trust in direct drives from Schaeffler Industrial Drives particularly in the machine tool, medical equipment, automation, robotics, food, packaging, printing machinery, textile machinery, productronics and measuring equipment industries.

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1 Legend of symbols

$2\tau_p$	–	Pole pair width
a	m/s^2	Direction-dependent acceleration
a_{acc}	m/s^2	Acceleration
B_S	mm	Width of the secondary part
c	kJ/kg · K	Specific heat capacity
dV/dt	l/min	Volume flow
F	N	Force
F_a	N	Attraction force
F_{acc}	N	Acceleration force, without friction
$F_{acc\ tot}$	N	Acceleration force, incl. friction
F_c	N	Continuous force, not cooled
F_{ca}	N	Displacement force per carriage
F_{cog}	N	Cogging force at I = 0
F_{cw}	N	Continuous force, cooled
F_{dec}	N	Braking force
F_{eff}	N	Effective force
F_{grind}	N	Machining force
F_L	N	Breakaway force
F_{max}	N	Max. force
F_p	N	Peak force
F_{pl}	N	Peak force, linear range
F_{RV}	N	Carriage displacement force
$F_{safe\ acc}$	N	Acceleration force, incl. friction and safety factor
$F_{safe\ eff}$	N	Effective force, incl. safety factor
F_{sw}	N	Stall force, cooled
F_{tot}	N	Total force
F_u	N	Ultimate force
F_{work}	N	Force at constant velocity
H	mm	Height without secondary part cooling
I	A	Motor current
$I_{c\ eff}$	A	Effective continuous current, not cooled
$I_{c\ red}$	A	Reduced continuous current, not cooled
$I_{cw\ eff}$	A	Effective continuous current, cooled
$I_{p\ eff}$	A	Effective peak current
$I_{pl\ eff}$	A	Effective peak current, linear range
$I_{sw\ eff}$	A	Effective stall current, cooled
$I_{u\ eff}$	A	Effective ultimate current
k_f	N/A	Force constant
k_m	$N/\sqrt{W}$	Motor constant, linear motors
$k_{\hat{u}}$	V/(m/s)	Back EMF constant, phase to phase
L	mH	Inductance, phase to phase
L_{CP}	mm	Length of cooling profiles
L_{CS}	mm	Length of the cover strip
L_P	mm	Length of the primary part
$L_{P\text{-}ACT}$	mm	Magnetically active length
m	kg	Mass to be moved
m_{EP1}	kg	Mass of the secondary part with cooling and cover strip
m_{EP2}	kg	Mass of the secondary part, with cover strip only
m_{EP3}	kg	Mass of the secondary part, with cooling only (kg)
m_P	kg	Mass of primary part
m_{part}	kg	Mass of workpiece, workpiece carrier, carriage and cable drag chain
m_S	kg	Mass of the secondary part, version M
m_{SP}	kg	Mass of the secondary part, version P
n	–	Number of carriages
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts
P_l	W	Power loss

$P_{l\ eff}$	W	Power loss
P_{lc}	W	Power loss at F_c
P_{lp}	W	Power loss at F_p
P_{lw}	W	Power loss at F_{cw}
Q	J	Heat
R	Ω	Ohmic resistance
R_{20}	Ω	Electrical resistance at +20 °C, phase to phase
s	m	Distance or position
s_{acc}	m	Acceleration distance
s_{dec}	m	Braking distance
SF_{acc}	–	Safety factor for peak force evaluation
SF_{eff}	–	Safety factor for effective force evaluation
s_{work}	m	Working stroke
t	s	Time
t_{acc}	s	Acceleration time
t_{dec}	s	Deceleration time
t_{stop}	s	Pause time
t_{tot}	s	Cycle time
t_{work}	s	Machining time
U_{DCL}	V	DC link voltage
v	m/s	Velocity
V	m^3	Volume
v_{lc}	m/s	Limiting velocity at $I_{c\ eff}$
v_{lp}	m/s	Limiting velocity at $I_{p\ eff}$ and U_{DCL}
$v_{lp\ 300}$	m/s	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V
$v_{lp\ 600}$	m/s	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V
v_{lw}	m/s	Limiting velocity at $I_{cw\ eff}$ and U_{DCL}
v_{lw300}	m/s	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V
v_{lw600}	m/s	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V
v_{work}	m/s	Machining speed
Δp	bar	Pressure drop
Δp_{CP}	bar/m	Pressure drop of the cooling profile
Δp_{EP}	bar	Pressure drop at the end piece
Δp_F	bar	Pressure drop, fittings
Δp_H	bar	Pressure drop, supply and return
Δp_P	bar	Pressure drop, primary part cooling
Δp_S	bar	Pressure drop, secondary part cooling
Δp_{tot}	bar	Pressure drop for the entire cooling system
$\Delta\vartheta$	K	Cooling medium temperature difference
$\Delta\vartheta$	K	Cooling water temperature difference
η	Pa · s	Dynamic viscosity
ϑ	°C	Temperature
ϑ_f	°C	Current feed temperature
ϑ_{max}	°C	Max. permissible winding temperature
ϑ_n	°C	Nominal response temperature
ϑ_{nf}	°C	Nominal feed temperature
ϑ_{PTC}	°C	Motor temperature switch-off threshold
ν	mm^2/s	Kinematic viscosity
ρ	kg/m^3	Density
Φ	W	Heat flow

2 L7 linear motors

The L7 series consists of 12 motors. The 12 sizes are derived from 4 design widths of 100 mm, 150 mm, 200 mm and 300 mm, combined with 3 design lengths of 350 mm, 500 mm and 650 mm. With high durability, reliability, energy efficiency and resource efficiency, L7 linear motors meet all the requirements of the current Ecodesign Directive 2009/125/EC.

Typical applications:

- milling machines
- turning machines
- laser machining
- surface and profile grinding machines
- centreless grinding machines
- out-of-round machining
- oscillating machining
- HSC axes
- PCB drilling machines

2.1 Performance capability

Loss-free motion

Transmission elements and coupling elements in the drive train introduce elasticity, backlash, friction or hysteresis. They generate power losses. Linear motors do not require transmission or coupling elements. As a result the force acts in the direction of motion without loss.

Constant force

An iron-core linear motor generates very high forces. These forces are effective from standstill up to the limiting velocity. The motor can cover a very wide characteristic range without the need for a gearbox.

Accuracy and dynamics

Direct position measurement via a measuring system, combined with the rigid mechanical design of linear motors, enables highly dynamic control behaviour as well as extremely accurate and highly dynamic positioning processes.

Short strokes

A linear motor has a theoretically infinite control stiffness. This allows the motor to perform short strokes and micro-movements at very high speeds. Such movements are very difficult or even impossible to achieve with a ball screw or rack-and-pinion drive due to inertia and backlash.

Fast movements

Thanks to the compact design, the mass is very low. The available force is very high and offers high dynamic controllability. This enables extremely high accelerations and maximum velocities. The resulting fast machining process increases productivity.

Compatibility

Linear motors from Schaeffler Industrial Drives are suitable for operation with many widely used control systems.

2.2 Operating costs

Minimal installation, adjustment and maintenance effort

A linear motor has no additional moving parts. The absence of additional moving parts reduces the installation, alignment and maintenance requirement for the drive assembly. A consistently clean and dry air gap between the primary part and and secondary, as well as the avoidance of thermal and electrical overload, help protect the motor. Under these conditions, the service life of the motor can exceed that of other components of a linear axis.

High availability

A linear motor is robust against loads in the direction of travel. The drive train remains wear-resistant even under the highest alternating loads and is therefore extremely durable. This reduces machine downtime.

Energy efficiency

A high copper density in the primary part and highly efficient water cooling reduce waste heat to a minimum. The low waste heat reduces energy consumption in the converter and recooling system. The converter feeds braking energy back into the system. This reduces energy consumption and lowers CO_2 emissions.

2.3 Design

Few components

A linear motor consists of a small number of robust components. This reduces the failure rate and increases the MTBF (mean time between failures).

High degree of flexibility

L7 linear motors are available with different windings and in 12 sizes. This allows the appropriate motor to be selected for each application.

Active temperature control

Primary or secondary part cooling integrates the motor into the machine’s temperature management system. This reduces temperature-related effects.

3

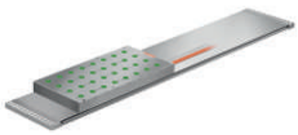
3 Characteristics of linear motors

Linear motors are made up of a primary part and a secondary part. The primary part contains an active coil system. The secondary part contains a permanent magnet system. In the conventional arrangement, the secondary part remains static. In the push rod arrangement, the secondary part moves. An energised primary part generates a force that acts on the secondary part as a result of the electromagnetic force.

A mechanical guidance system enables operation of the motor. The guidance system maintains the air gap between the primary part and the secondary part and absorbs the attraction force between them. A measuring system for detecting the position of the moving part is also required. Due to the wide range of application requirements, linear motor series have been developed with a wide variety of primary parts and secondary parts.

In terms of their structural design, linear motors can essentially be divided into iron-core and ironless motors. The magnetic system is either U-shaped or a conventional flat secondary part. Linear motors generate a consistently high force over a wide operating range. The force is determined by the active air gap area between the primary part and the secondary part, and by the structure. The designer selects the appropriate motor and, if necessary, a cooling system in accordance with the performance requirements. Conventional electric motors are classified according to power. Linear motors are classified according to force.

1 Characteristics of linear motors

Motor series	Features	Design
L7	Linear motors with extremely high efficiency and force density • F_p up to 24000 N • F_{cw} up to 11000 N • design lengths: 350 mm, 500 mm and 650 mm • design widths: 100 mm, 150 mm, 200 mm and 300 mm	

4 General motor characteristic values

4.1 Efficiency criteria

The winding and size of a linear motor influence the power losses ➤62 | 12. Although linear motors generate a high force when stationary, they do not deliver any mechanical power. As a result, there is no reason to state the efficiency. The motor constant k_m describes the relationship between force and generated power loss or temperature increase, and thus the efficiency of a linear motor.

The motor constant k_m specified in the performance data is valid only under the following conditions:

- within the linear control range (from 0 to $I_{pl\ eff}$) ➤15 | 3
- at standstill and at low velocities
- at room temperature

An increase in temperature, and therefore in winding resistance, reduces the efficiency of the motor. In addition to copper losses, iron losses occur at higher velocities. These iron losses consist of frequency-dependent remagnetisation losses and eddy current losses. The motor constant k_m does not take iron losses into account. Iron losses become relevant in the limiting velocity range and must therefore be considered.

1

$$P_l = \left(\frac{F}{k_m}\right)^2$$

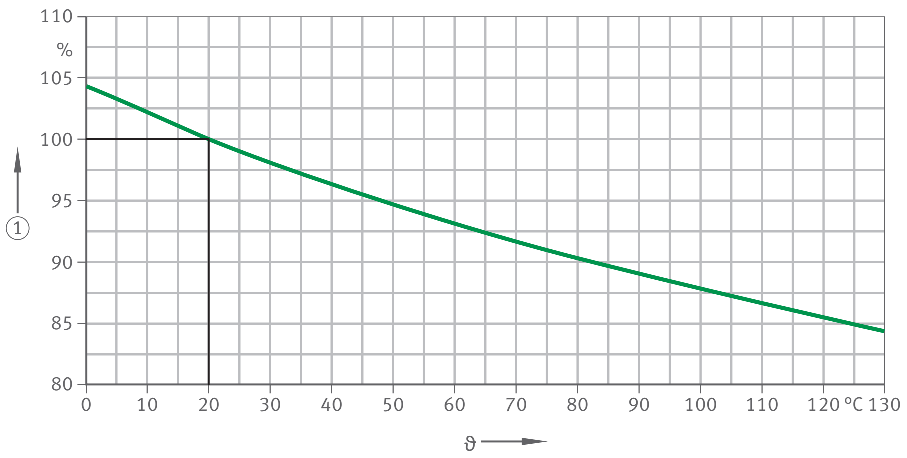
F	N	Force
k_m	N/√W	Motor constant, linear motors
P_l	W	Power loss

The ohmic resistance, and therefore the winding temperature of a motor, influence the motor constant k_m.

In the performance data, the motor constant k_m is specified for +20 °C. The characteristic curve shows the relative temperature-dependent change in the value of the motor constant.

4

1 Motor constant k_m as a function of temperature ϑ



1	Related motor constant	ϑ	Temperature

Thermal behaviour

An increase in temperature raises the winding resistance and reduces the value of the motor constant. At +130 °C, the value of the motor constant decreases to 0,84 times the reference value at +20 °C. At constant current or constant force, a higher power loss occurs in a heated motor compared to a cold motor. This power loss further increases the motor temperature.

4.2 Winding designs and dependencies

The maximum velocity of the motor is primarily determined by the series design.

The following designs are available:

- iron-core
- laminated iron core
- ironless

Within a given series, the size, DC link voltage and winding version influence the maximum velocity.

Voltage drops within the motor increase the voltage requirement as velocity rises. At the limiting velocity, the voltage requirement corresponds to the DC link voltage of the servo converter. Beyond this point, the velocity decreases rapidly. The higher the DC link voltage and the smaller the voltage constants associated with the winding $k_{\hat{u}}$, the higher the achievable limiting velocities. Since the voltage constant and force constant are correlated, higher velocity requirements at the same force result in an increased power requirement for the motor. In the performance data, one or more standard windings are predefined for each motor size for different limiting velocities and dynamic requirements at a fixed DC link voltage U_{DCL} ➤62 | 12.

A reduction in the DC link voltage reduces the limiting velocity.

4.3 Force-velocity characteristic curve

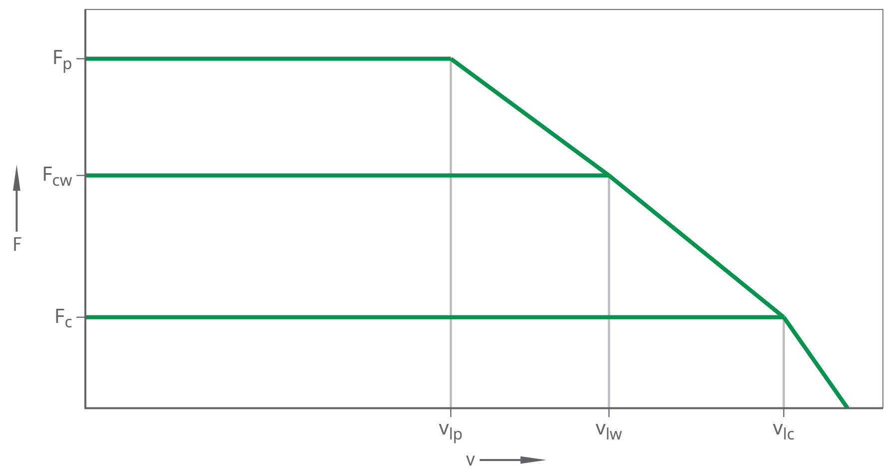
A force-velocity characteristic curve shows the winding-specific velocity limits as a function of force at constant DC link voltage without field weakening at various operating points.

The characteristic curve does not show the duty cycle and the associated thermal behaviour of the motor. The characteristic curve only represents the operating points that the motor can approach at a winding temperature of +20 °C. Operating points with forces greater than F_{cw} are subject to time restrictions in order to protect the primary part from overheating.

Forces up to F_p are taken into account in the design. At forces between F_p and F_u, an excessively high secondary part output temperature may lead to demagnetisation. F_u is therefore specified in the performance data. The velocity v_{lu} associated with F_u is not relevant in practice and is therefore not included in the performance data. For this reason, neither F_u nor v_{lu} are shown in force-velocity characteristic curves.

Velocities above 1 m/s require, in heat-sensitive applications, consideration of frequency-dependent eddy current losses. These losses occur in the secondary part. Eddy current losses can be taken into account by using secondary part cooling ➤31 | 8.3.

2 Force-velocity characteristic curve



F	Force	v	Velocity
F_p	Peak force	v_{lp}	Limiting velocity at $I_{p\ eff}$
F_{cw}	Continuous force, cooled	v_{lw}	Limiting velocity at $I_{cw\ eff}$
F_c	Continuous force, not cooled	v_{lc}	Limiting velocity at $I_{c\ eff}$

! Force at v = 0 m/s
A Z-axis without mass compensation is an example of a continuously acting force at standstill. The continuously acting force at standstill F_s is limited. If the position of the primary part relative to the secondary part is unfavourable, certain windings may be overloaded at standstill when operating above 70 % of the cooled continuous force.

Control reserve

All specified motor velocities relate to a constant DC link voltage U_{DCL}. In the case of frequency converters without a stabilised DC link, U_{DCL} is not constant. The operating point must therefore be provided with a control reserve as a function of the DC link voltage fluctuation. Typically, for frequency converters without a stabilised DC link, the velocity at the operating point should not exceed approx. 80 % of the motor’s possible velocity at this operating point.

The limiting velocity v_{lc} at $I_{c\ eff}$ and F_c is important for understanding the characteristic curve but does not need to be considered in practice. Further information on the operating conditions of the velocity limits at the corresponding DC link voltage ($v_{lp\ 600}$, $v_{lp\ 300}$, $v_{lw\ 600}$ and $v_{lw\ 300}$), as well as the associated forces (F_u, F_p, F_{cw}, F_c and F_{sw}), and currents ($I_{u\ eff}$, $I_{p\ eff}$, $I_{cw\ eff}$, $I_{c\ eff}$ and $I_{sw\ eff}$), can be found in the glossary ➤84 | 14.

4.4 Force-current characteristic curve

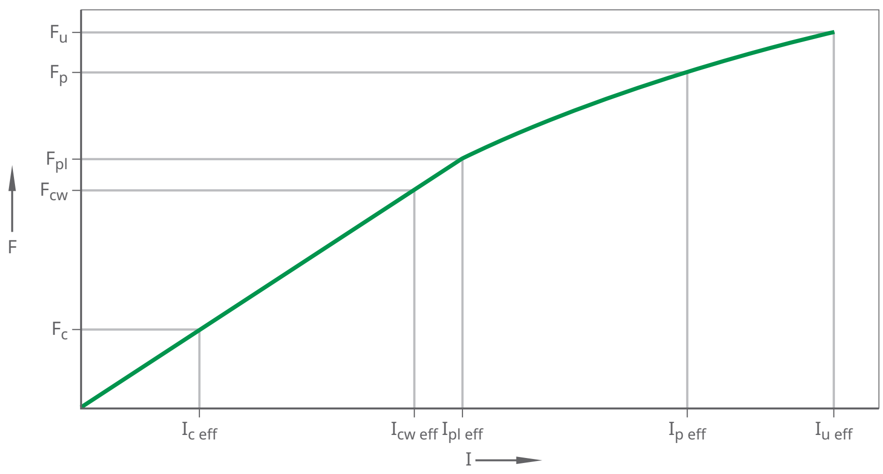
Linear range

A motor current in the range from 0 A to $I_{pl\ eff}$ generates a force with a linear relationship. The characteristic curve between the force-current points 0,0 and F_{pl}, $I_{pl\ eff}$ is a straight line. The current $I_{pl\ eff}$ generates the peak force in the linear range F_{pl}. Within this range, the user can calculate the power loss using the motor constant k_m. The force constant k_f shows the linear increase of the characteristic curve. Using the force constant k_f, the user can calculate the generated force for a given current. The value of the linear ultimate current $I_{pl\ eff}$ is independent of temperature. The value depends on the series and the winding version. It can be lower or higher than the value of the cooled continuous current $I_{cw\ eff}$. The linear ultimate current $I_{pl\ eff}$ and the associated peak force in the linear range F_{pl} are important for understanding the characteristic curve. However, as these values can generally be neglected in practice, they are not stated in the performance data.

Non-linear range

A motor current in the range from $I_{pl\ eff}$ to $I_{u\ eff}$ generates a force with a non-linear relationship. The characteristic curve between the force-current points F_{pl}, $I_{pl\ eff}$ and F_u, $I_{u\ eff}$ is curved. The non-linearity of the force-current characteristic curve in this range is caused by the saturation of a motor’s magnetic circuits. In this range, the characteristic curve has a variable and significantly lower slope than the force constant k_f. The motor can be operated for a few seconds up to the operating point F_p, $I_{p\ eff}$. This is the maximum operating point for acceleration processes. As the permanent magnets are at risk of demagnetisation, the limiting point F_u, $I_{u\ eff}$ must not be exceeded.

3 Force-current characteristic curve



F	Force	I	Motor current
F_u	Ultimate force	$I_{u\ eff}$	Effective ultimate current
F_p	Peak force	$I_{p\ eff}$	Effective peak current
F_{pl}	Peak force, linear range	$I_{pl\ eff}$	Effective peak current, linear range
F_{cw}	Continuous force, cooled	$I_{cw\ eff}$	Effective continuous current, cooled
F_c	Continuous force, not cooled	$I_{c\ eff}$	Effective continuous current, not cooled

5

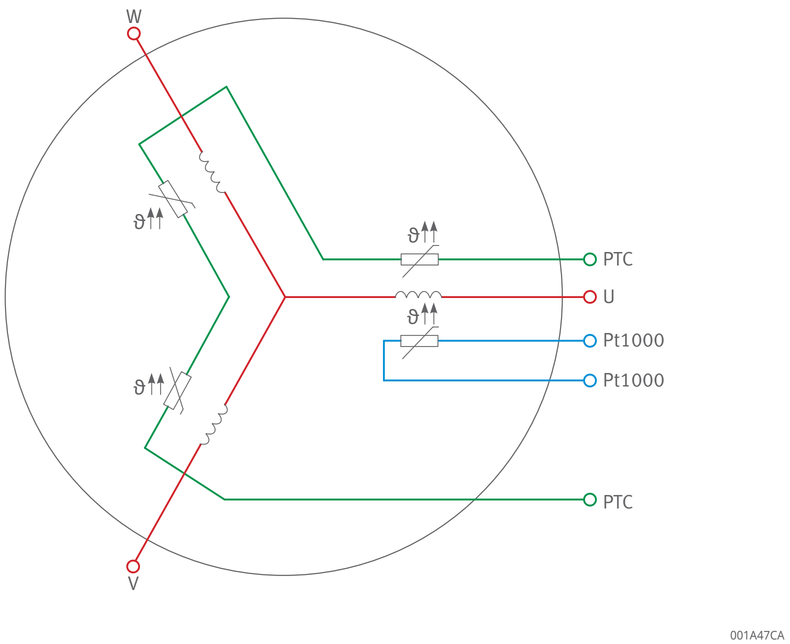
5 Thermal motor protection

5.1 Monitoring circuits I and II

Users often operate direct drives at their thermal performance limit. In addition, an unpredictable overload can occur during operation. The overload results in a current load that is higher than the permissible continuous current. In the event of overload, the effective motor current, the square mean value I^2t, must not exceed the permissible continuous motor current. For short-term overcurrent, the power electronics must have an I^2t motor protection model to control the motor current. This indirect temperature monitoring is very fast and reliable. During motor commissioning, the user must ensure that the I^2t monitoring is switched on.

Motors from Schaeffler Industrial Drives must be protected by means of motor temperature monitoring. Monitoring circuit I of the standard version contains 3 PTC sensors, connected in series, on the 3 phase windings. Monitoring circuit II also includes a Pt1000 sensor on one phase in the motor. This sensor enables pre-warning thresholds.

4 Standard connection of triplet PTC and Pt1000



The PTC and Pt1000 sensors have basic isolation from the motor. The sensors are not suitable for direct connection to PELV circuits or SELV circuits in accordance with DIN EN 61800-5-1.

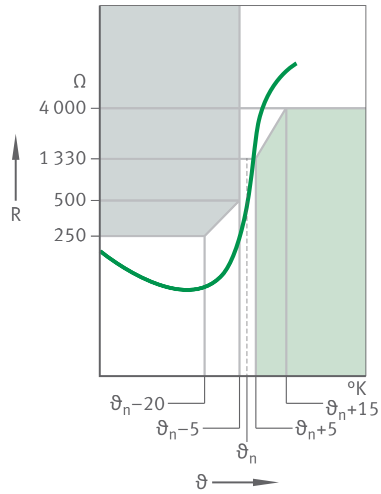
5.2 Monitoring circuit I

A PTC is a thermistor. A PTC has a thermal time constant of a few seconds. In contrast to that of the Pt1000, the resistance of the PTC rises very sharply when the nominal response temperature ϑ_n is exceeded. The resistance increases to a multiple of the cold value when the nominal response temperature is exceeded.

When using a triple PTC, i.e. three PTC sensors connected in series, the total resistance changes significantly. This considerable change also occurs if only one sensor exceeds the response temperature ϑ_n. The use of three PTC sensors ensures that the motor can still be shut down safely by a thermistor motor protection relay under asymmetrical phase load, e.g. at standstill. The thermistor motor protection relay typically trips between 1,5 kΩ and 3,5 kΩ, thus triggering a controller stop.

The PTC sensors detect the overtemperature of each winding with a deviation of only a few degrees.

5 PTC temperature characteristics



R	Resistance	ϑ	Temperature
ϑ_n	Nominal response temperature		

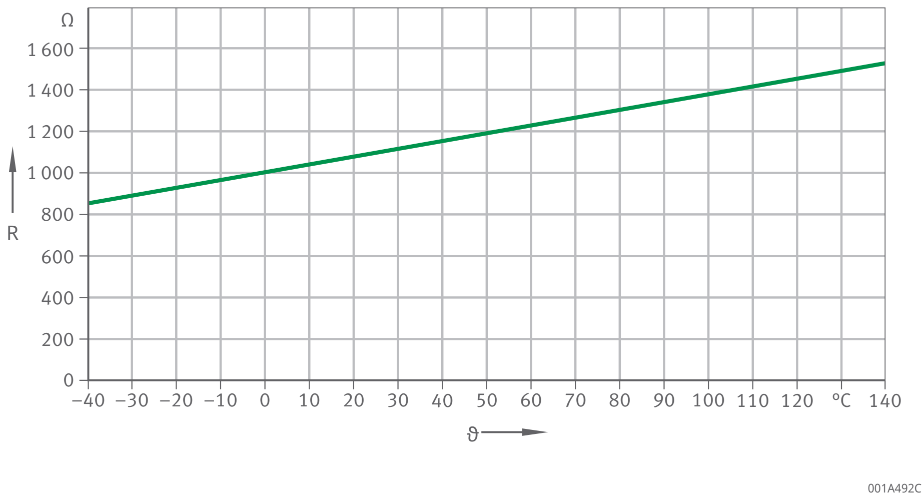
The thermistor motor protection relay also responds if the resistance in the PTC circuit is too low. The excessively low resistance may indicate a defect in the monitoring circuit. The thermistor motor protection relay ensures safe galvanic isolation of the controller from the PTC sensors in the motor. The thermistor motor protection relay is not included in the scope of delivery of the motor. PTC sensors of temperature monitoring circuit I are not suitable for temperature measurements. Monitoring circuit II is suitable for temperature measurements.

! In principle, a thermistor motor protection relay connected to the servo converter must evaluate the PTC sensors for temperature protection of the motor.

5.3 Monitoring circuit II

The Pt1000 is a platinum measuring resistor temperature sensor. This sensor makes use of the temperature dependence of the electrical resistance of platinum. EN 60751 describes the sensor characteristic.

6 Pt1000 temperature characteristics

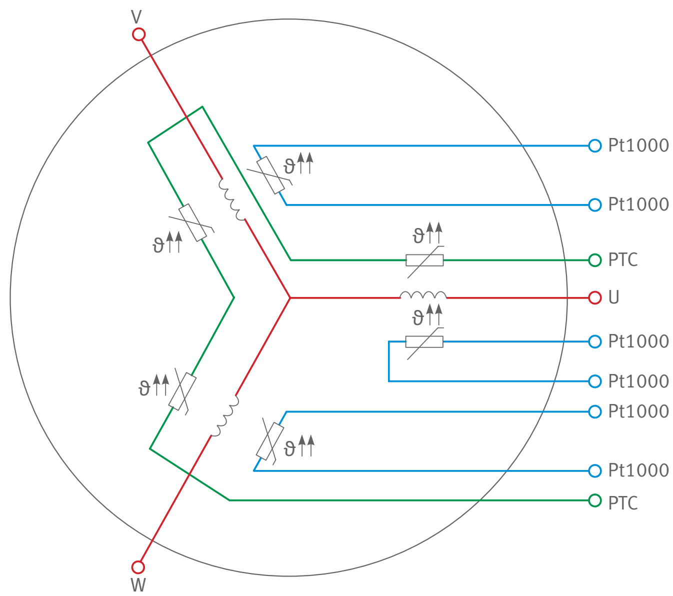


R	Resistance	ϑ	Temperature

The thermal time constant is a few seconds in the installed state. Pre-warning threshold and a shutdown limit are entered in the controller and protect the motor from overtemperature. The pre-warning threshold prevents immediate shutdown by the thermistor motor protection relay.

At standstill, depending on the application, constant currents can flow through the windings of the motor. The pole position determines the magnitude of the constant currents. The motor is not heated homogeneously through this dependency. Unmonitored windings may overheat. A Pt1000 sensor can only monitor one phase. The use and evaluation of three Pt1000 sensors ensure the monitoring of all phases. For applications that regularly reach the loading limit at standstill, Schaeffler Industrial Drives recommends the use and evaluation of three Pt1000 sensors.

7 Connection of triplet PTC and 3 Pt1000



6 Electrical connection technology

6.1 Cable connections

Screw connections on the front face of the L7 linear motors serve as connection points for the power supply cables. Drawings in the product tables section show the position of the screw connections ➤62|12. The cable is 2 m long from the motor outlet. Other cable lengths are available on request. The motor continuous current $I_{cw\ eff}$ at P_{Iw} determines the required cable cross-section ➤19|▦4.

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The cables have the following characteristics:

- shielded
- resistant to oil and coolant courtesy of polyurethane outside surface
- flame resistant
- suitable for drag chain use

The cable ends are open with ferrules in the standard version. Application-specific cable outlets are possible.

▦2 Motor cable connections, standard

Cross-section	Continuous current	Diameter	min. bending radius, fixed	min. bending radius, flexible	Mass
–	A	mm	mm	mm	g/m
4G0,75	10,4	8	40	80	95
4G1,5	16,1	9	45	90	140
4G2,5	22	10,5	52,5	105	210
4G4	30	12,5	62,5	125	296
4G6	37	14,5	72,5	145	416
4G10	52	17	85	170	644
4G16	70	20,5	102,5	205	997

▦3 Motor connection assignments

Designation	Assignment
1/U	Phase U
2/V	Phase V
3/W	Phase W
GNYE	PE

The sensor cable enables temperature monitoring using PTC and Pt1000 sensors. The cable ends are supplied open with ferrules in the standard version. Application-specific cable outlets are available.

▦4 Sensor cable connections, standard

Cross-section	Temperature monitoring	Diameter	min. bending radius, fixed	min. bending radius, flexible	Weight
–	–	mm	mm	mm	g/m
Sensor 4×0,14	P [1]	4,8	24	36	40
Sensor 10×0,14	T [2]	6,7	34	50	87

[1] P = 1 Pt1000 + 3 PTC ➤54|11

[2] T = 3 Pt1000 + 3 PTC ➤54|11

5 Connection assignments, sensor variant P

Designation	Assignment
WH	PTC
BN	PTC
GN	Pt1000
YE	Pt1000

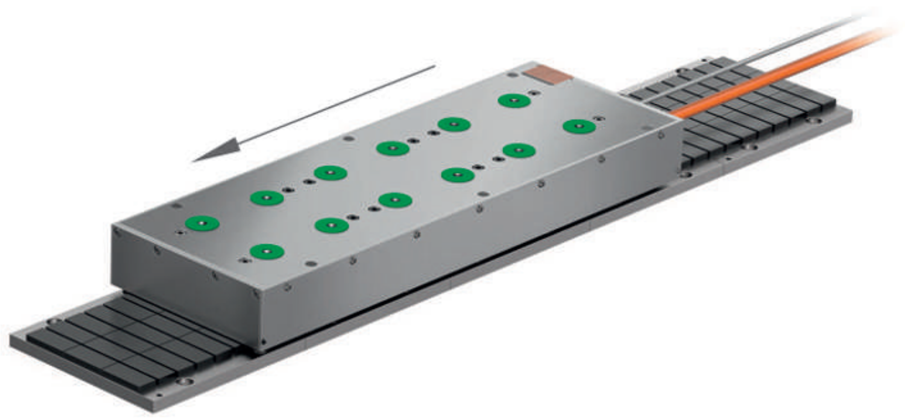
6 Connection assignments, sensor variant T

Designation	Assignment
WH	PTC
BN	PTC
GN	Pt1000-1
YE	Pt1000-1
GY	Pt1000-2
PK	Pt1000-2
BU	Pt1000-3
RD	Pt1000-3

6.2 Direction of motion of the motor

For all 3-phase motors, the electrically positive direction of motion of the primary part corresponds to a clockwise rotating field. In a clockwise rotating field, the phase voltages are induced in the sequence U → V → W.

8 Electrically positive direction of motion of the moving primary part



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6.3 Commutation

Synchronous motors should be operated with commutation where possible. Schaeffler recommends commutation that is based on the measuring system, since this is supported by modern servo drives and controllers.

6.4 Isolation strength and overvoltage phenomena

Schaeffler Industrial Drives develops, designs, and manufactures motors in accordance with the Low Voltage Directive 2014/35/EU. The motors meet the requirements of the Electromagnetic Compatibility (EMC) Directive 2014/30/EU. The motors are intended for proper operation within a PDS (Power Drive System) in accordance with DIN EN 61800-5-1.

The motor insulation systems of the motors are designed to overvoltage category III and optimised for maximum life. The dielectric strength of the insulation systems is checked prior to delivery. Modern test methods, such as measurement of the partial discharge inception voltage, ensure long-term service life and performance.

Once installed, the motor forms part of the PDS, which consists of the motor, motor cable, and converter components such as the supply module, regenerative modules, drive controller, and filters. Unintended and unpredictable effects may occur within the PDS. Controller manufacturers often provide recommendations and project planning information that must be observed and followed by the user. Non-compliance may result in premature failure of the insulation systems in the motor or converters.

The following measures ensure safer operation, regardless of the converter:

- **short cable lengths and extensive cable shielding coverage**
  Short cable lengths and extensive cable shielding coverage help to prevent overvoltages caused by high-frequency reflections in the motor cable. Motor cables with a length of 10 m or more between the motor and converter increase the likelihood of overvoltages. Schaeffler Industrial Drives recommends measuring the voltage at the motor connection terminals using suitable high-voltage equipment during machine commissioning.
- **correct motor selection**
  The motors must be selected according to the DC link voltage of the converter. In most cases, the DC link voltage is 600 V. A lower DC link voltage reduces the dynamic response and maximum velocity. A DC link voltage of 720 V and above, or installation heights above 2000 m require a reinforced insulation system. In such cases, please contact Schaeffler Industrial Drives. Motors with inductances significantly above 50 mH, measured from phase to phase, may only be used following case-by-case assessment by the converter manufacturer and Schaeffler Industrial Drives. Otherwise, resonances in the PDS and insulation damage due to voltage peaks may occur.

Instructions from the converter manufacturer must be observed. If any of the following applies, this must be specified in the request. Alternatively, measurement of the transient overshoot can be carried out during commissioning on site.

- PDS with multi-axis converter modules or regulated supplies:
  here, electrical oscillations relative to earth potential and the resulting voltage load can damage the motor's insulation system.
- applications in which more pronounced insulation damage has occurred in the past
- applications in which countermeasures already exist

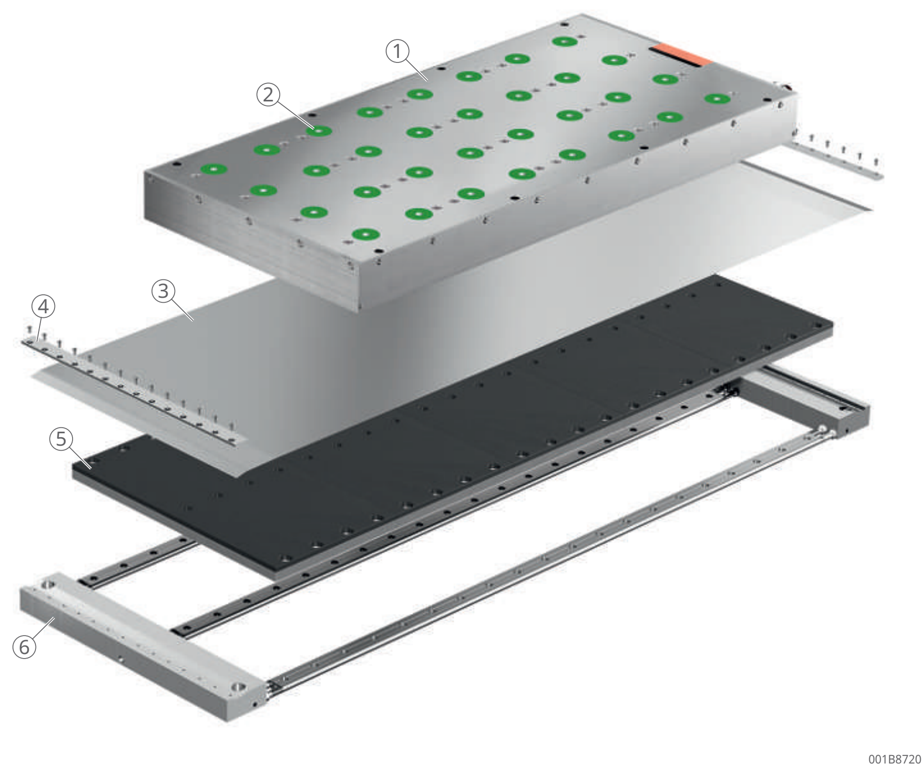
For a DC link voltage of 600 V to 720 V, the transient overshoot between the motor phases must not exceed 1370 V. The peak-to-peak voltage between the motor phases must not exceed 2800 V.

Line reflections and electrical oscillations caused by controlled power supply overlap when measurements are taken between a motor phase and earth potential. During evaluation, only the peak-to-peak voltage should be considered. The peak-to-peak voltage between the motor phases must not exceed 2350 V.

7 Motor cooling, fundamentals

The motor cooling of the L7 linear motors has been developed with a focus on applications in machine tools. Particularly in HSC (High Speed Cutting), HPC (High Performance Cutting) and grinding, increasingly higher feed forces are required while maintaining maximum precision. The drive system must generate feed forces with maximum efficiency. Heat generated by power losses must be dissipated immediately in order to prevent inaccuracies in the machine caused by heat input. The design of the overall system, consisting of heat-generating and heat-dissipating components, controls the heat flow within the motor. Two cooling circuits dissipate heat from the L7 linear motors quickly and efficiently. The first cooling circuit consists of primary part cooling on the mounting side of the primary part. The second cooling circuit consists of secondary part cooling beneath the secondary part. The secondary part cooling ensures that no heat is transferred into the machine or the surrounding structure.

9 L7 linear motor with primary part cooling and secondary part cooling



1	Primary part with integrated cooling	2	Plastic spacer, green
3	Cover strip	4	Wedge strip
5	Secondary part	6	Secondary part cooling

To minimise thermally induced deformation and changes in machine geometry in machine tools, the measures listed below have proven effective:

- Thermal insulation:
  Spacers made of green plastic are arranged above the motor and thermally isolate the primary part from the mounting plate of the surrounding structure by means of an air gap ➤22 | 9.
- Temperature compensation:
  L7 primary parts are designed with thermal symmetry. As a result, there is only a small temperature gradient between the left and right sections or between the front and rear sections of the motor. This reduces excessive thermally induced tilting or pitching of the axis.
- Active temperature control:
  Secondary parts can optionally be equipped with a cooling facility and can be easily incorporated into the cooling system. Depending on the requirements, additional cooling of the component on which the secondary parts are mounted may not be necessary.

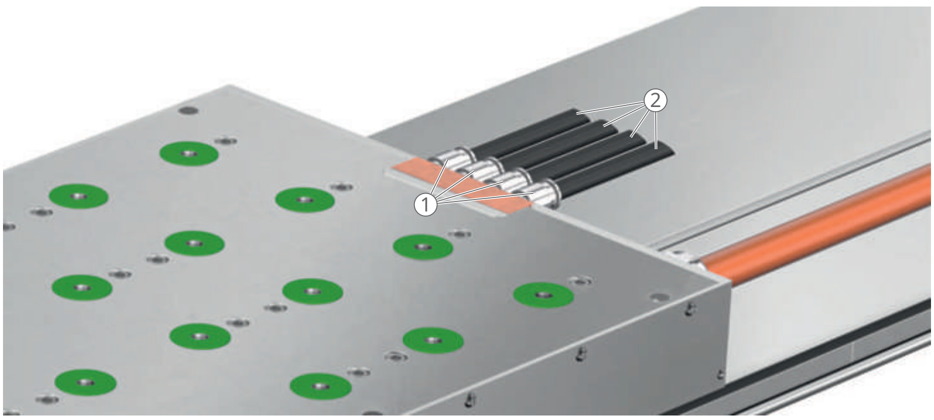
An L7 linear motor fully supports these measures.

7.1 Primary part cooling

A cooling circuit developed for machine tools typically uses water, a water–glycol mixture, or in individual cases oil as the cooling medium. The cooling circuit is connected to a recooling system or the machine's cooling system. The cooling medium travels from the inlet to the outlet through internal channels of the primary part cooling system.

For large motors, such as size 650-300, the primary part cooling consists of 2 cooling circuits. 2 cooling circuits achieve the required volume flow dV/dt and must be connected in parallel. Internal threads G $^1/_8$ are used as connections. Standard commercial push-in fittings can be used. Examples of fastening types include Festo QS-1/8-10-I with hex socket or Rectus one-hand quick-release coupling, series 21.

10 L7 primary part cooling, design width 300 mm



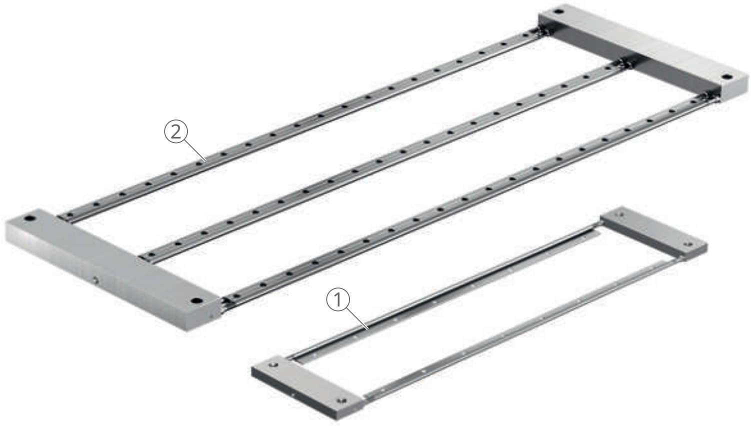
1	4x Festo QS-1/8-10-I	2	4x 10 mm hose

7.2 Secondary part cooling

Accuracy requirements are continuously increasing, particularly in demanding applications such as high-performance cutting of integral aircraft components, dry machining, or the production of complex housing parts. The machine type and machining process determine the permissible temperature fluctuations.

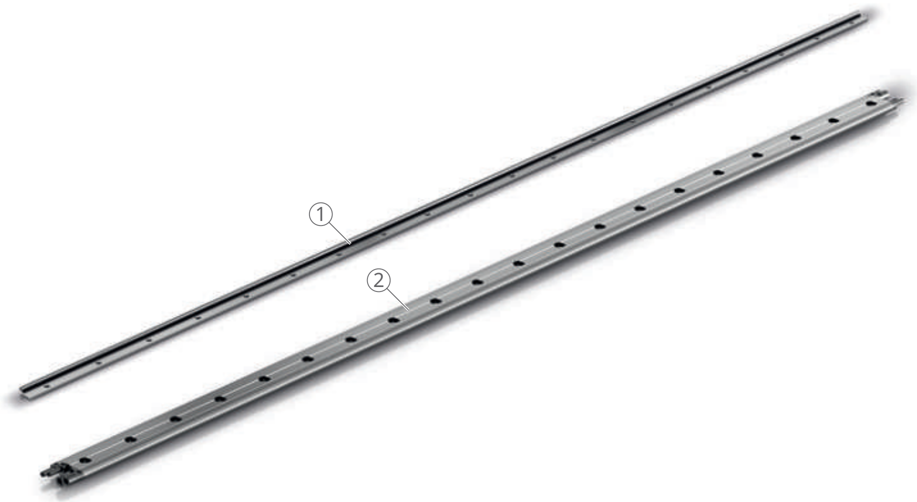
Permissible temperature fluctuations in the machine bed are typically in the range of ±0,5 °C to ±1 °C for universal milling machines. For HSC milling machines or boring mills, the requirements may be even more stringent. Permissible temperature fluctuations may be limited to ±0,2 °C to ±0,5 °C. Secondary part cooling enables compliance with these requirements. An L7 secondary part cooling consists of 2 end pieces and the associated cooling profiles. For design widths of 100 mm and 150 mm, 2 profiles are used, each with one cooling channel. For design widths of 200 mm and 300 mm, 3, profiles are used, each with 2 cooling channels. Plug connectors connect the cooling profiles to the end pieces.

11 L7 secondary part cooling



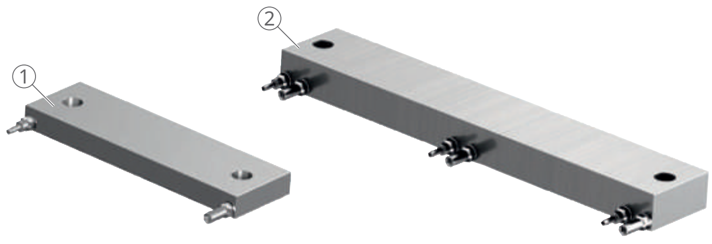
1	For design widths 100 mm and 150 mm	2	For design widths 200 mm and 300 mm

12 Cooling profile for secondary part cooling



1	For design widths 100 mm and 150 mm	2	For design widths 200 mm and 300 mm

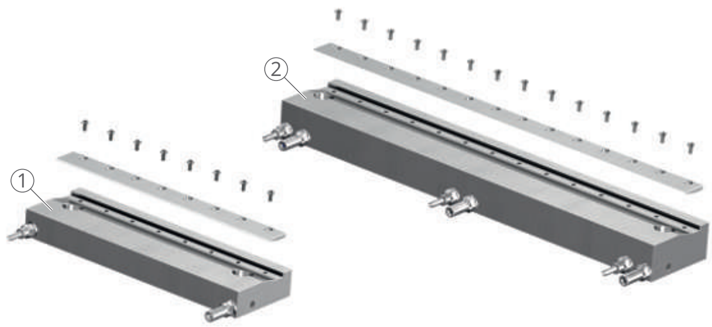
13 End pieces for secondary part cooling



1	For design widths 100 mm and 150 mm	2	For design widths 200 mm and 300 mm

End pieces with wedge strips secure a cover strip.

14 End pieces with wedge strips for secondary part cooling and cover strip



1	For design widths 100 mm and 150 mm	2	For design widths 200 mm and 300 mm

7.3 Cooling media and their influence on cooling

The values in the performance data are based on water as the cooling medium. The use of a cooling medium that differs significantly from water results in reduced heat dissipation and therefore also a change in F_{cw}. Schaeffler Industrial Drives provides support, on request, in designing the application and determining the achievable motor data.

For design using a customer-specific cooling medium, the following information is required:

- type and density
- specific heat capacity
- kinematic viscosity
- technical data sheet including composition

When using cooling media with a significantly higher viscosity than water, the effects on cooling must be assessed before use. If necessary, motor parameters such as $I_{cw\ eff}$ or F_{cw} must be adjusted. The data for the medium used must be applied and the expected temperatures must be taken into account.

7

Water

Water is the most commonly used cooling medium. Water has a high specific heat capacity and is inexpensive. Water with additives that prevent corrosion and biological deposits in the cooling circuit is preferable to all other cooling media. Additives such as COOL CONCENTRATE or COOL X hardly affect properties such as density and viscosity. Water with one of these additives is a very efficient cooling medium with a specific heat capacity of 4,1 kJ/kg · K. This value approximately corresponds to the value for water.

7 Material properties of water

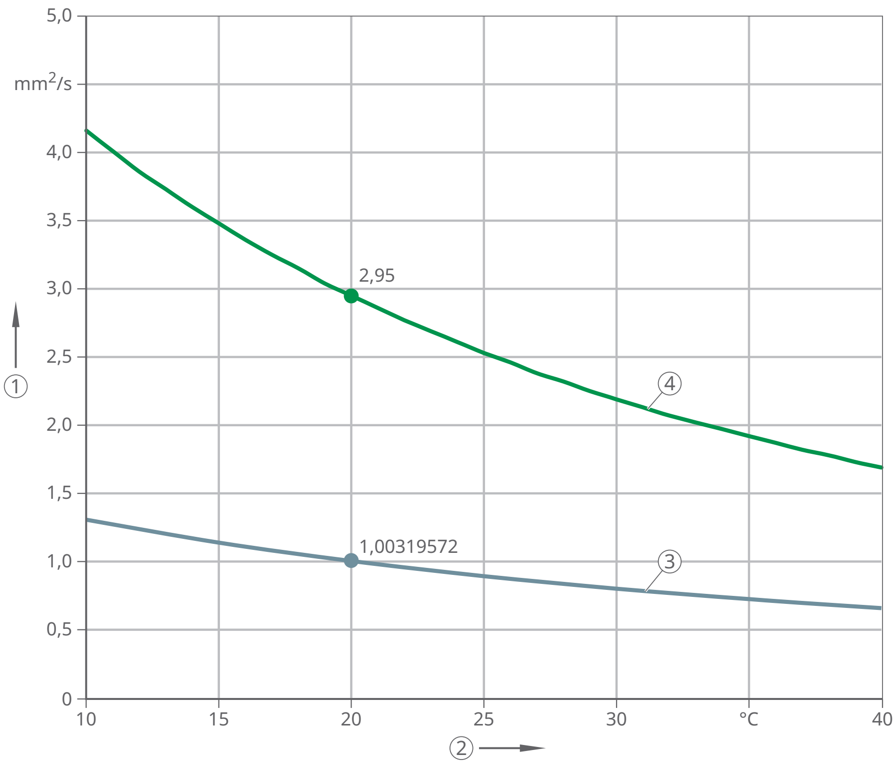
Temperature	Density [1]	Specific heat capacity	Dynamic viscosity	Kinematic viscosity
°C	kg/m^3	kJ/kg · K	Pa · s	mm^2/s
+20 [2]	998,21	4,1840	0,0010014	1,00319572
+25	997,05	4,1813	0,00088982	0,892452736
+30	995,65	4,1798	0,00079705	0,800532316

[1] According to DIN 1306, secondary conditions such as air pressure and gravitational acceleration apply 1 g, pressure p_n = 1,01325 bar

[2] Reference temperature

A mixture of water and glycol has a lower freezing point than that of water and prevents corrosion. This mixture is often used for cold environments or applications in which frost protection is required. Due to the higher viscosity of the water-glycol mixture compared with that of pure water, there is a higher pressure loss in the pipe system. The circulating pump must deliver a correspondingly higher pressure.

15 Dependence of kinematic viscosity on temperature



1	Kinematic viscosity	2	Temperature
3	Cooling medium: 100 % water	4	Cooling medium: 60 % water, 40 % ethylene glycol

Example:

A mixture of 40 % ethylene glycol, e.g. Antifrogen N, and 60 % water has a freezing point of –25 °C and a kinematic viscosity that is 2,95 times higher than that of water. The recommended flow rate can only be achieved with a significantly higher pressure. Correction factors can be used for a rough estimate.

8 Correction factors for ethylene glycol

Concentration	Freezing point	Correction factor for pressure difference
%	°C	–
20	–9	1,14
30	–16	1,23
40	–25	1,33
44	–30	1,38

7

When using this mixture, the pressure drops in the example ➤29|8 must be corrected to values 33 % higher. The exact values of the cooling medium used must always be observed.

Oils

Oils are used as cooling media in some industrial applications. The application determines which oil is the right one. If oil is used, the volume flow necessary for cooling must always be achieved.

Upon request, Schaeffler Industrial Drives can provide help with sizing. The chemical compatibility of all components must be checked by the customer.

7.4 Influence of nominal data on the supply temperature and cooling medium

The continuous current $I_{cw\ eff}$ specified for cooled operation refers to the nominal supply temperature ϑ_{nf} of the cooling medium and is stated in the performance data ➤62|12.

Higher supply temperatures ϑ_f reduce the cooling capacity and, thus, also the continuous current. The reduced continuous current $I_{c\ red}$ is calculated from the following quadratic relationship:

2 Reduced continuous current

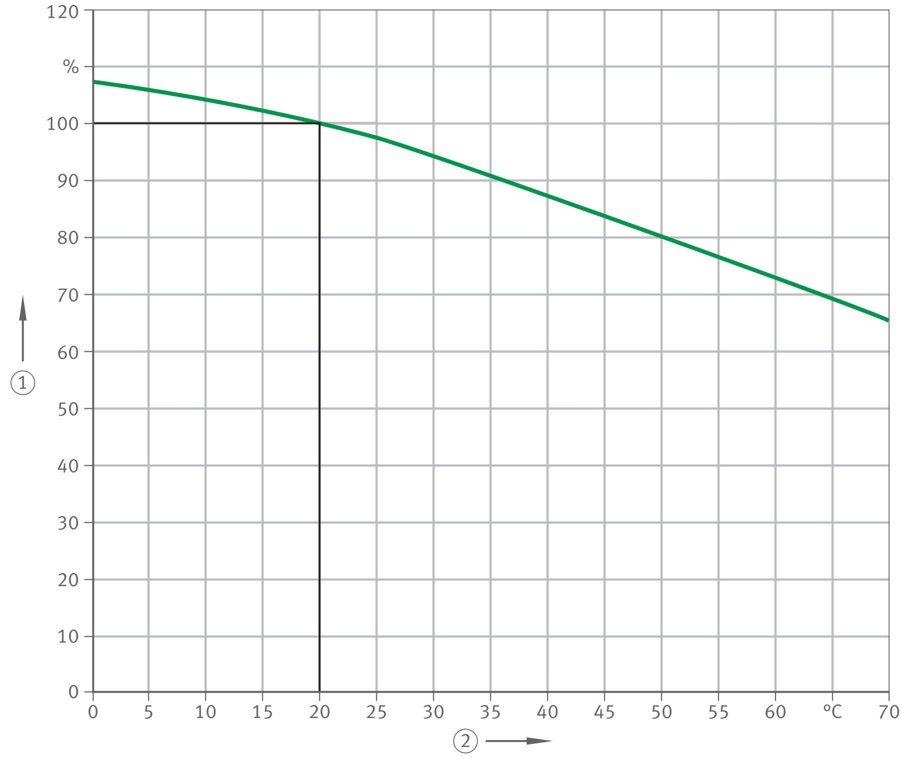
$$\frac{I_{c\ red}}{I_{cw\ eff}} = \sqrt{\frac{\vartheta_{max} - \vartheta_f}{\vartheta_{max} - \vartheta_{nf}}}$$

$I_{c\ red}$	A	Reduced continuous current
$I_{cw\ eff}$	A	Effective continuous current, cooled
ϑ_{max}	°C	Max. permissible winding temperature
ϑ_{nf}	°C	Nominal feed temperature
ϑ_f	°C	Current feed temperature

The use of customer-specific cooling media changes the dissipatable power loss and therefore the continuously available continuous force cooled F_{cw}. Engineers at Schaeffler Industrial Drives will, upon request and based on the specified material properties, determine the influence of the cooling medium used.

7

16 Relative continuous current $I_{c\ red}$ / $I_{cw\ eff}$ as a function of supply temperature ϑ_f
(ϑ_{nf} = +20 °C)



1	Relative continuous current $I_{c\ red}$ / $I_{cw\ eff}$ in %	2	Current supply temperature ϑ_f
$I_{c\ red}$	Reduced continuous current	ϑ_{nf}	Nominal supply temperature
$I_{cw\ eff}$	Continuous current, cooled		

8 Motor cooling, example

This example illustrates the design of the recooler and its integration into the machine. Using the example of a *feed axis in a universal machine tool*, parameters such as density, heat capacity, volume flow and dissipatable power loss are determined. A cooling medium other than water must be evaluated.

8.1 Step 1, requirements

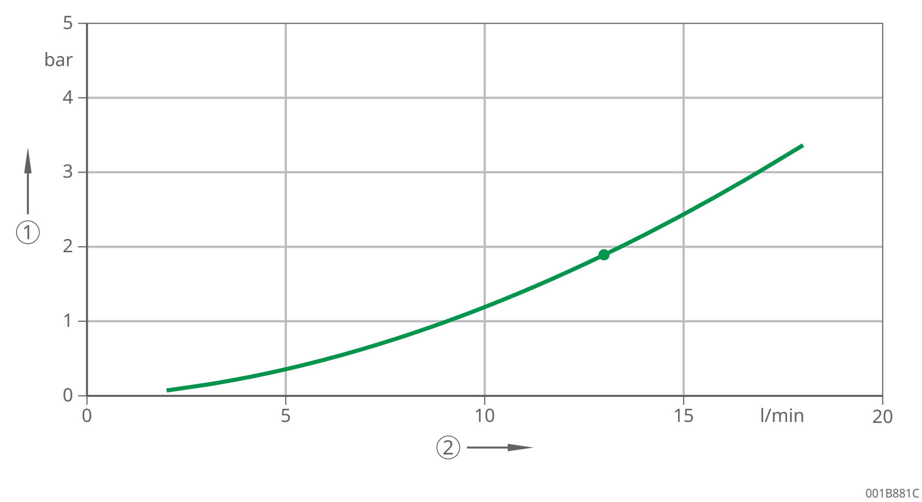
Motor data are taken from the data sheet or from the performance data ➤62 | 12.

9 Application example for linear motor L7-3P-650-300-Z3.8H with 10 secondary parts

Description	Value
Power loss P_{lw} at F_{cw}	5357 W
Cooling water temperature difference $\Delta\vartheta$	5,9 K
Recommended volume flow dV/dt	13 l/min [1)]
Pressure drop Δp, corresponds to Δp_P	1,9 bar

1) 2x 6,5 l/min for two cooling circuits in parallel.

17 Pressure drop L7-3P-650-300-Z3.8H



1	Pressure drop	2	Volume flow

Cooling medium used:

- water + 11 % COOL CONCENTRATE with properties similar to water

Requirements from system integration:

- Machine bed should be subjected to as little heat input as possible. Secondary part cooling is used.
- The pressure of the cooling medium should be approx. 5 bar at the operating point, with a maximum system pressure of 10 bar.
- Length of the cooling supply line and cooling return line approx. 5 m, D = $^1/_2$", with a pressure drop Δp_H of approx. 0,32 bar

8.2 Step 2, primary part cooling, volume flow and pressure drop

Motor cooling data are specified in the performance data ➤62 | 12.

8

Determination of the volume flow dV/dt

A large proportion of the total power loss P_{lw} is dissipated via the volume flow. A small portion of the heat is transferred to the secondary part and the mounting base or the secondary part cooling system. The volume flow is calculated on the basis of the calorimetric equation. For calculating the temperature difference between supply and return, the values for pure water are used.

The basic calorimetric equation is:

ƒ3

$$Q = c \cdot m \cdot \Delta\vartheta$$

where

ƒ4

$$m = \rho \cdot V$$

This results in:

ƒ5

$$Q = c \cdot \rho \cdot V \cdot \Delta\vartheta$$

Differentiating with respect to time yields the form applicable to the cooling system:

ƒ6

$$\Phi = c \cdot \rho \cdot \frac{dV}{dt} \cdot \Delta\vartheta$$

By substituting the temperature difference $\Delta\vartheta$ and the power loss P_{lw} for the heat flow Φ, the recommended volume flow is obtained:

ƒ7

$$\frac{dV}{dt} = \frac{P_{lw}}{c \cdot \rho \cdot \Delta\vartheta}$$

c	kJ/kg · K	Specific heat capacity
dV/dt	l/min	Volume flow
P_{lw}	W	Power loss at F_{cw}
$\Delta\vartheta$	K	Cooling medium temperature difference
ρ	kg/m^3	Density

$\Delta\vartheta$ is the temperature difference between the cooling supply and the cooling return. To keep temperature differences within the motor small, $\Delta\vartheta$ should preferably be 5 K and must not exceed 10 K. In this example, the value according to the performance data is 5,9 K.

For the linear motor L7-3P-650-300-Z3.8H, the following values apply:

- Power loss P_{lw} = 5357 W
- Temperature difference $\Delta\vartheta$ = 5,9 K

The specific heat capacity and density for water at +20 °C are taken from the corresponding table ➤26|▦7.

ƒ8

$$\frac{dV}{dt} = \frac{5357}{4{,}1840 \cdot 998{,}21 \cdot 5{,}9} = 0{,}21739\ \frac{l}{s} = 13{,}04\ \frac{l}{min}$$

Determining the pressure drop Δp_P

The pressure drop Δp_P, corresponding to Δp in the performance data, results from flow resistances. Flow resistances arise, for example, from wall friction and turbulence in pipelines, as well as in associated fittings and components. In simplified terms: the pump of the cooling unit builds up the pressure, and depending on the volume flow and design, an operating point dV/dt relative to Δp is established. The cooling medium used in the example, water + 11 % COOL CONCENTRATE, has properties largely similar to those of water. Therefore, the values for pressure drops from the performance data can be used. For the motor L7-3P-650-300-Z3.8H, a pressure drop Δp_P of 1,9 bar in the primary part results for a volume flow of approx. 13 l/min.

8

8.3 Step 3, secondary part cooling, volume flow and pressure drop

Determination of the volume flow dV/dt

The application determines the requirements for the secondary part cooling. The expected power loss due to heat radiation, also referred to as heat input, from the primary part to the secondary part is taken from the corresponding table ➤31 | ▦10. For the motor used in this example, L7-3P-650-300, the heat input is 460 W.

▦10 Expected heat input from the primary part to the secondary part

Primary part	**Heat input P**
	W
L7-3P-350-100	94
L7-3P-350-150	126
L7-3P-350-200	167
L7-3P-350-300	229
L7-3P-500-100	142
L7-3P-500-150	189
L7-3P-500-200	250
L7-3P-500-300	344
L7-3P-650-100	189
L7-3P-650-150	252
L7-3P-650-200	334
L7-3P-650-300	460

8

In the example, a simplified calculation is performed using a temperature difference $\Delta\vartheta$ of 0,5 K and a heat to be dissipated Φ of 460 W. The minimum required volume flow dV/dt is:

ƒ9

$$\frac{dV}{dt} = \frac{P_{lw}}{c \cdot \rho \cdot \Delta\vartheta}$$

c	kJ/kg · K	Specific heat capacity
dV/dt	l/min	Volume flow
P_{lw}	W	Power loss at F_{cw}
$\Delta\vartheta$	K	Cooling medium temperature difference
ρ	kg/m³	Density

ƒ10

$$\frac{dV}{dt} = \frac{460}{4{,}1840 \cdot 998{,}21 \cdot 0{,}5} = 0{,}22028\ \frac{l}{s} = 13{,}22\ \frac{l}{min}$$

The location of heat generation in the secondary part depends on the application. In a linear axis for a milling machine, the heat input is concentrated at a single point, as almost 100 % of the heat is transferred via the primary part and the axis exhibits minimal movement. An axis that moves frequently at high speed generates eddy current losses in the secondary part due to iron losses. Eddy current losses in the secondary part are negligible in most applications. In the ultra-precision range or in applications with a duty cycle of more than 50 % and v > 1 m/s, eddy current losses should be analysed in greater detail. Eddy current losses depend on velocity and can be estimated using the table values ➤32|▦11. Eddy current losses are taken into account in the cooling performance of the secondary part in proportion to their time share.

Example, primary part L7-3P-650-300

If an axis moves at a velocity of 1,15 m/s for 60 % of the cycle time, 60 % is taken into account in the secondary cooling performance. The table value is 608 W. 364,8 W is taken into account.

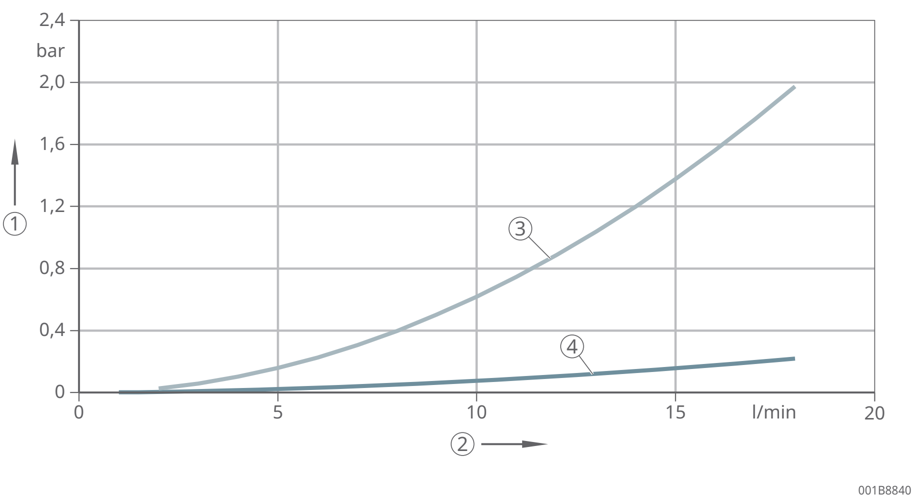
▦11 Eddy current losses

Primary part	**Velocity v**		
	0,46	**1,15**	**1,84**
	m/s		
	Eddy current losses in the secondary part		
	W		
L7-3P-350-100	19	101	238
L7-3P-500-100	28	152	357
L7-3P-650-100	37	203	476
L7-3P-350-150	28	152	357
L7-3P-500-150	42	228	536
L7-3P-650-150	56	304	714
L7-3P-350-200	37	203	476
L7-3P-500-200	56	304	714
L7-3P-650-200	74	406	952
L7-3P-350-300	56	304	714
L7-3P-500-300	84	456	–
L7-3P-650-300	112	608	–

Determining the pressure drop Δp_s

The pressure drops for an end piece can be taken from the following diagram. Diagrams for other sizes are available in the product tables ➤80 | 13. The pressure drop specified in the diagram for the cooling profiles is the sum of the pressure drops of all cooling profiles connected in parallel.

18 Pressure drop, secondary part cooling, design width 300



1	Pressure drop	2	Volume flow
3	End piece	4	Cooling profile, length 1 m

At a volume flow of approx. 13 l/min, this results in a pressure drop Δp_{EP} of 1,05 bar for the end piece and a pressure drop Δp_{CP} of 0,15 bar/m for the cooling profile ➤33 | 18.

In this example, with 10 secondary parts, secondary part cooling with 2 end pieces is used. L_{CP} is calculated as 1820 mm ➤60 | 11.2.

This results in the following for the entire secondary part cooling:

11

$$\Delta p_S = 2 \cdot \Delta p_{EP} + \frac{L_{CP}}{1000} \cdot \Delta p_{CP}$$

Δp_{CP}	bar/m	Pressure drop of the cooling profile
Δp_{EP}	bar	Pressure drop at the end piece
Δp_S	bar	Pressure drop, secondary part cooling
L_{CP}	mm	Length of cooling profiles

12

$$\Delta p_S = \left(2 \cdot 1{,}05\right) + \left(\frac{1820}{1000} \cdot 0{,}15\right) = 2{,}37 \approx 2{,}4 \text{ bar}$$

8.4 Step 4, cooling configuration

Consideration of additional pressure drops

The specific values for the pressure drops of the motor components are available in the performance data ➤62 | 12.

Pressure drops in connectors, connection fittings and distribution hoses for supply and return lines must also be taken into account. The values are available on the respective manufacturers' websites.

Push-in fittings:
Standard models for 10-mm hoses exhibit a pressure drop Δp_F of 0,04 bar per connection at 6,5 l/min. This results in a pressure drop of 0,08 bar per primary cooling circuit.

Hose:
A $^1/_2$" hose for supply and return lines with a length of approx. 5 m each causes a pressure loss Δp_H of approx. 0,16 bar, resulting in a total of 0,32 bar at 13 l/min.

8

Cooling configuration

The configuration of the individual cooling elements depends on various criteria. These criteria include volume flow and pressure drop, the cooling medium used, the spatial layout, the cooling concept and the impact on other machine axes. In the design example, the required volume flows for primary part cooling and secondary part cooling are comparable, each at approx. 13 l/min. Therefore, the cooling elements can be connected in series. The pressure drop for the entire cooling system is calculated as follows:

ƒ13

$$\Delta p_{tot} = \Delta p_P + \Delta p_S + \Delta p_F + \Delta p_H$$

Δp_F	bar	Pressure drop, fittings
Δp_P	bar	Pressure drop, primary part cooling
Δp_S	bar	Pressure drop, secondary part cooling
Δp_H	bar	Pressure drop, supply and return
Δp_{tot}	bar	Pressure drop for the entire cooling system

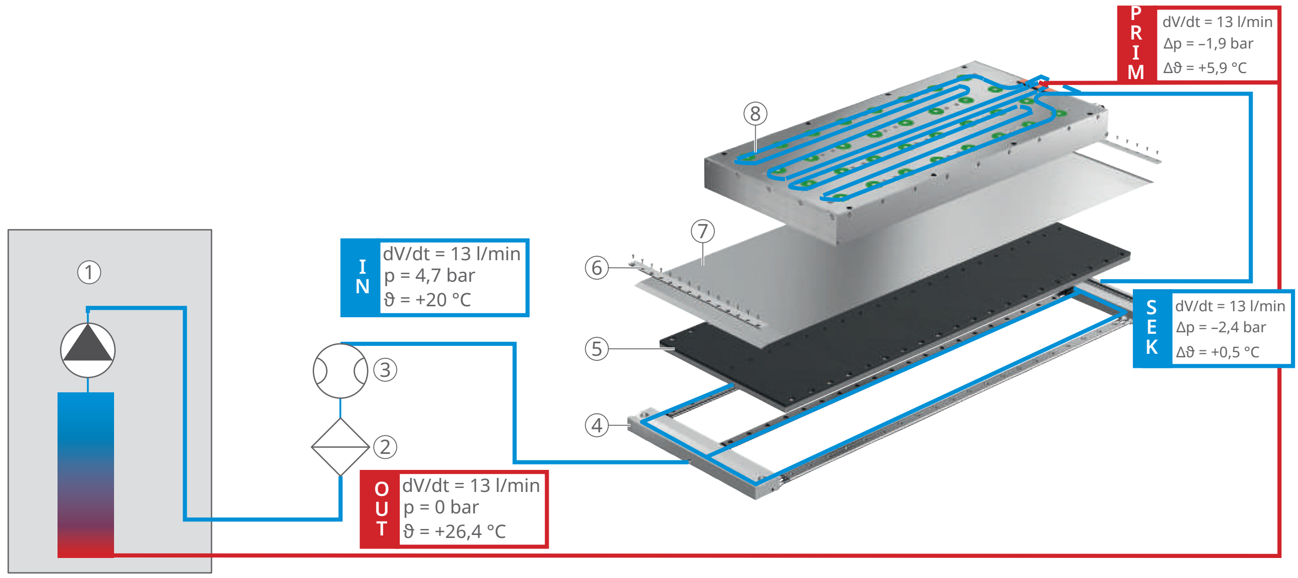
ƒ14

$$\Delta p_{tot} = 1{,}9 + 2{,}4 + 0{,}08 + 0{,}32 = 4{,}7 \text{ bar}$$

Configuration: series connection

Preferred sequence of cooling components: recooler → secondary part cooling → primary part cooling → recooler.

19 Series connection of the cooling components



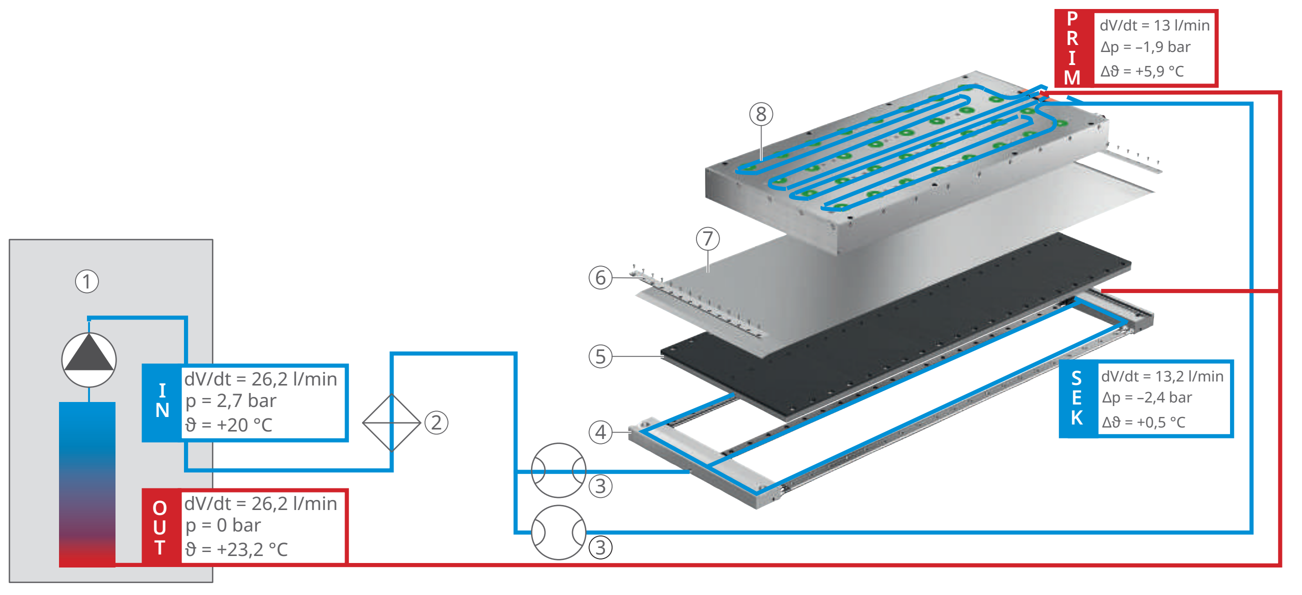
1	Recooler	2	Filter
3	Flow meter	4	Secondary part cooling
5	Secondary part	6	Wedge strip
7	Cover strip	8	Primary part cooling, blue
IN	Data at the inlet of the cooling system	OUT	Data at the outlet of the cooling system
PRIM	Data at the primary part cooling	SEK	Data at the secondary part cooling

With $\Delta p_{tot} \approx 4{,}7$ bar and the applied volume flow of 13 l/min, the recooler can now be requested or designed accordingly.

Alternative configuration: parallel connection

In the design example, the cooling circuits with different operating points, dV/dt and Δp, can also be connected in parallel.

20 Parallel connection of the cooling components



1	Cooler with pump	2	Filter
3	Flow meter	4	Secondary part cooling
5	Secondary part	6	Wedge strip
7	Cover strip	8	Primary part cooling, blue
IN	Data at the inlet of the cooling system	OUT	Data at the outlet of the cooling system
PRIM	Data at the primary part cooling	SEK	Data at the secondary part cooling

In a parallel connection, each cooling element must have approximately the same pressure drop. The volume flows of both cooling elements relative to each other must also be evaluated.

When cooling elements are connected in parallel, one cooling circuit influences the other. The greater the difference in pressure drop, the greater this influence. The cooling circuit with the lowest hydraulic resistance draws a greater share of the total system's volume flow. In the example, the volume flow in the primary part is reduced and the heat is not dissipated as intended, causing the temperature difference Δϑ to rise above 5,9 K.

As countermeasures, hydraulic balancing, a pressure regulator or a deliberate overpressure can be used, whereby the minimum volume flow in the primary part is set during commissioning. Collective fault messages and flow monitoring devices are generally recommended.

8.5 Step 5, recooler

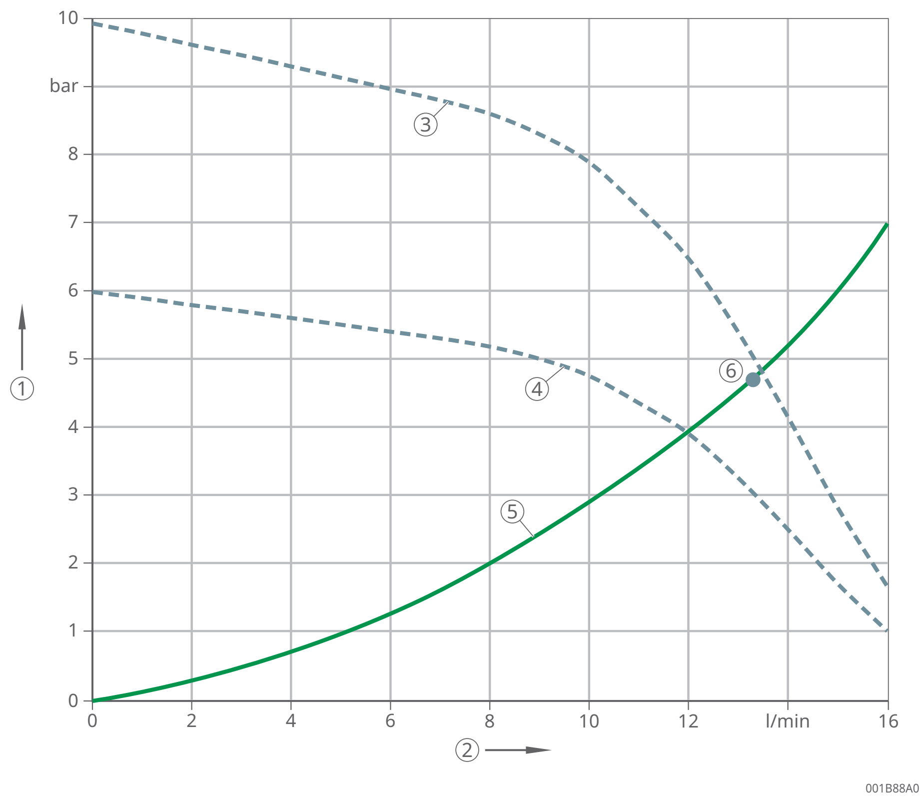
Based on the calculated data and requirements, the following key parameters result for a cooler in this example:

- Cooling capacity: 5360 W
- Operating pressure: 4,7 bar at a volume flow of 13,2 l/min
- Temperature difference between supply and return: approx. 6,4 K

A possible pump characteristic curve is shown in the diagram ➤37 | 21. For better understanding, the calculated operating point is shown in conjunction with the pressure drop characteristic curve of the motor cooling circuit. Characteristic curves of the individual assemblies, such as primary part cooling and secondary part cooling, which are combined according to the configuration and arrangement, can be found in the motor data section ➤62 | 12.

Based on the operating point at 4,7 bar and a volume flow of 13,2 l/min, a suitable cooler option can be determined. With pump 1, the requirements are met. An operating point of approx. 4,7 bar at 13,2 l/min is achieved. With lower-performance pumps, the desired operating point would not be achieved and the volume flow would be reduced, in this case to only approx. 10 l/min. Pump manufacturers usually provide recommendations and project planning information that must be observed and followed by the user.

21 Possible pump characteristic curves of a recooler



1	Pressure drop	2	Volume flow
3	Pump 1	4	Pump 2
5	Motor cooling circuit	6	Operating point

9 Arrangement of motors

9.1 Parallel operation of multiple motors on one axis

Distributing the motor force across multiple motors is beneficial in certain applications. 2 configurations are possible: a parallel tandem arrangement and an anti-parallel arrangement, i.e. mirror-image Janus arrangement, of the primary parts. The primary parts are mechanically coupled by mounting them on a carriage of an axis. Schaeffler Industrial Drives must be consulted before planning parallel operation.

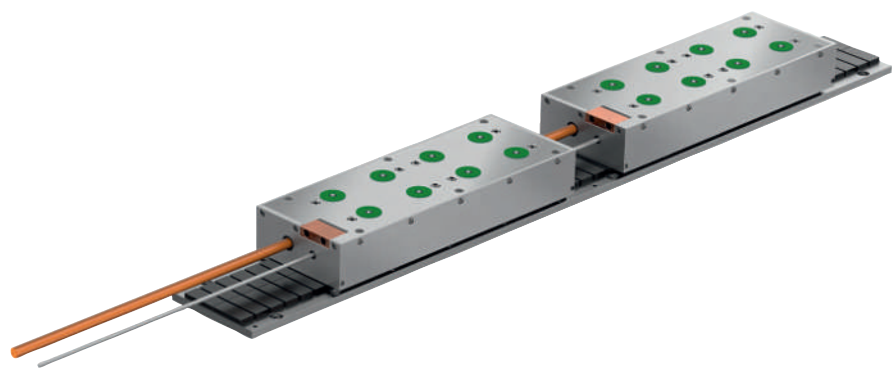
9.2 Primary part alignment

Primary parts must be aligned along their longitudinal axis with the axis of symmetry. Lateral offset is not permitted. The user must ensure that parallel motors are aligned in phase with one another. Any other alignment reduces the force constant and efficiency as a function of velocity due to induced short-circuit currents.

9.3 Master and slave

When using multiple motors on one axis, the first motor is designated as the **master**. This motor defines the positive direction of travel of the axis. All additional motors are designated as **slaves**. Based on this definition, the following mechanical configurations can be implemented:

22 Tandem arrangement



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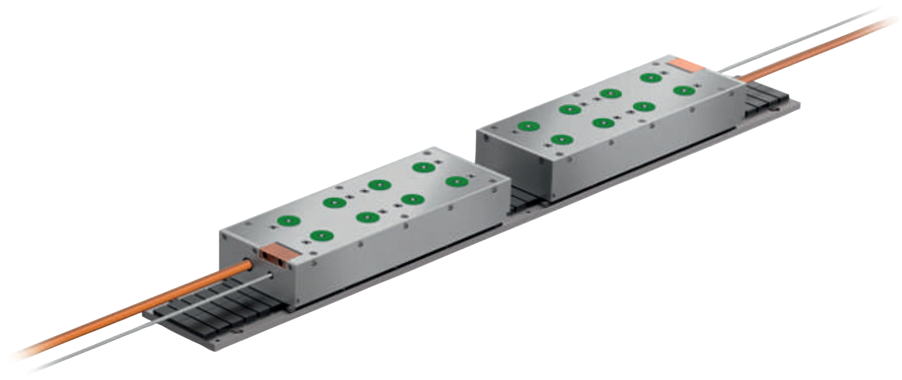
23 Janus arrangement



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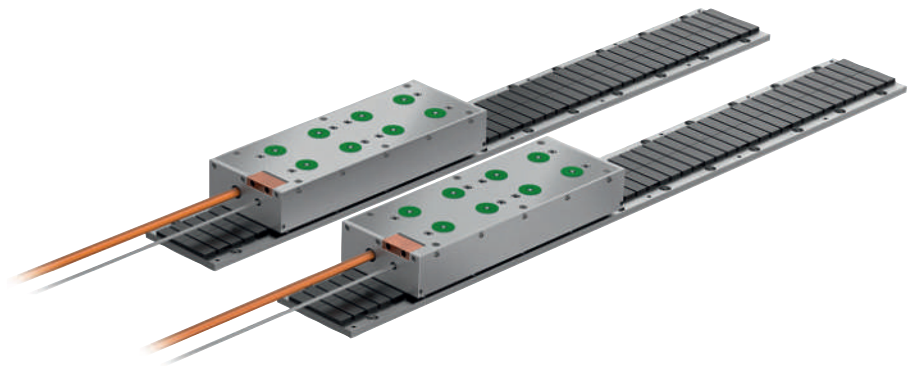
24 Parallel arrangement



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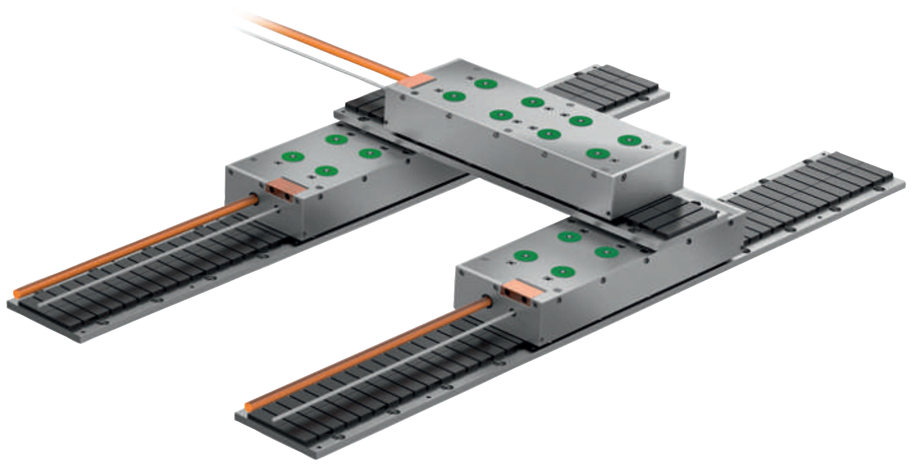
25 Anti-parallel arrangement

001B8910

26 Portal arrangement



10 Motor selection, example

10.1 Application example

This example describes the short-stroke grinding of the mounting structure, also referred to as a *fir-tree profile*, on the root section of a turbine blade.

The surface to be ground has a length of 100 mm. Each side of the component is machined in 20 double strokes. For economical production, a cycle time per grinding stroke of t_{tot} = 0,4 s is required.

27 Turbine blades mounted in an engine

001B8956

Objective

Minimum total cost of ownership (TCO): higher productivity and lower unit costs, including reduced CO_2 costs and energy costs

10.2 Motion cycle

The motion sequence consists of 3 consecutive positioning movements followed by a final dwell phase.

Step 1 (acc):

The motor accelerates the mass m with force F to v_{work}, minus the carriage displacement force F_{RV} and the breakaway force F_L.

Step 2 (work):

The workpiece moves at a constant velocity v_{work}, is machined, and reaches the end point of the machining process. During this movement, the motor only needs to overcome the carriage displacement force F_{RV} and the machining force F_{grind}.

Step 3 (dec):

The motor decelerates the workpiece carrier with force F_{dec}, supported by the carriage displacement force F_{RV}, to v = 0.

Step 4 (stop):

The motor remains stationary until the grinding wheel has been adjusted or moved out of the path.

After step 4, the motor returns to the starting position and the workpiece is machined in the process.

Motion cycle, key data

From the workpiece geometry, the working stroke is defined as s_{work} = 100 mm. To achieve the required surface quality, the grinding wheel used must move over the workpiece at a machining speed v_{work} of 1,66 m/s. During machining, a machining force F_{grind} of 20 N is applied. Before the next working stroke, the grinding machine requires t_{stop} = 0,06 s to adjust the grinding wheel. The maximum available time for a production cycle is: cycle time t_{tot} = 0,4 s.

12 Key data for the example

Designation	Symbol	Value	Comment
Working stroke	s_{work}	0,1 m	–
Machining speed	v_{work}	1,66 m/s	–
Pause time	t_{stop}	0,06 s	–
Cycle time	t_{tot}	0,4 s	max.

The time for step 4 is known. The distance and velocity for step 2 are known. The time for step 2 is calculated as follows:

15

$$t_{work} = \frac{s_{work}}{v_{work}}$$

s_{work}	m	Working stroke
t_{work}	s	Machining time
v_{work}	m/s	Machining speed

16

$$t_{work} = \frac{0{,}1\ \text{m}}{1{,}66\ \text{m/s}} = 0{,}06\ \text{s}$$

The sum of step 2 and step 4 is 0,12 s.

The duration of step 1 and step 3 is identical. This results in:

17

$$t_{acc} = t_{dec} = \frac{t_{tot} - t_{stop} - t_{work}}{2}$$

t_{acc}	s	Acceleration time
t_{dec}	s	Deceleration time
t_{stop}	s	Pause time
t_{tot}	s	Cycle time
t_{work}	s	Machining time

18

$$t_{acc} = t_{dec} = \frac{0{,}4\ \text{s} - 0{,}06\ \text{s} - 0{,}06\ \text{s}}{2} = 0{,}14\ \text{s}$$

All times and velocities are known. When presented as a table, this results in:

13 Motion cycle

Symbol	Unit	Step 1 (acc)		Step 2 (work)		Step 3 (dec)		Step 4 (stop)	
		Start	End	Start	End	Start	End	Start	End
Δt	s	–	0,14 [1]	–	0,06 [2]	–	0,14 [3]	–	0,06 [4]
t	s	0	0,14	0,14	0,2	0,2	0,34	0,34	0,4
v	m/s	0	1,66	1,66	1,66	1,66	0	0	0

1) t_{acc}: acceleration time

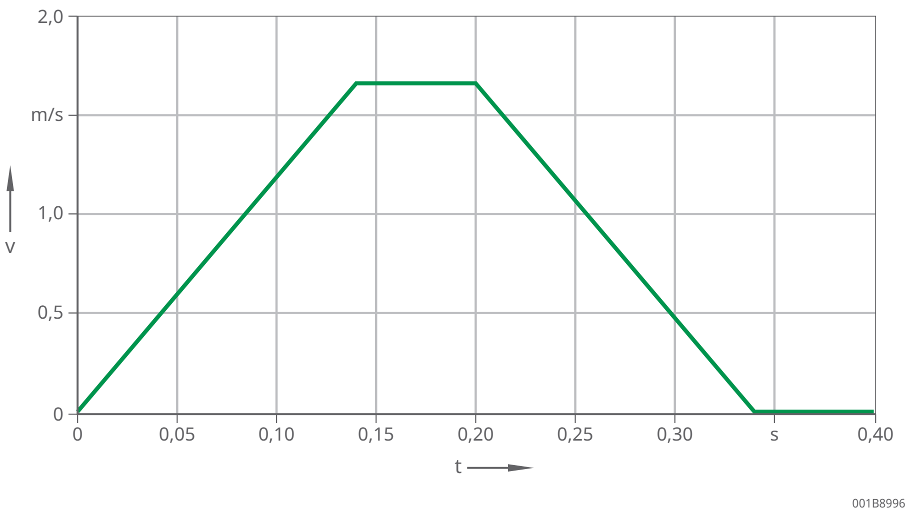
2) t_{work}: machining time

3) t_{dec}: deceleration time

4) t_{stop}: pause time

It is recommended to represent the desired motion cycle in order to identify any critical points.

28 Time profile of the travel velocity



v	Velocity	t	Time

10.3 Required acceleration

The acceleration required to reach the working velocity v_{work} within a given time can be calculated using the available distance and the specified time:

19

$$a = \frac{2s}{t^2}$$

However, since only the velocity v_{work} and the time t_{acc} are given, the required acceleration can be calculated as follows:

20

$$a_{acc} = \frac{v_{work}}{t_{acc}}$$

a_{acc}	m/s^2	Acceleration
t_{acc}	s	Acceleration time
v_{work}	m/s	Machining speed

f 21

$$a_{acc} = \frac{1,66}{0,14} = 11,86\ m/s^2$$

The table is extended to include the now known acceleration:

14 Motion cycle

Symbol	Unit	Step 1 (acc)		Step 2 (work)		Step 3 (dec)		Step 4 (stop)	
		Start	End	Start	End	Start	End	Start	End
Δt	s	–	0,14 [1)]	–	0,06 [2)]	–	0,14 [3)]	–	0,06 [4)]
t	s	0	0,14	0,14	0,2	0,2	0,34	0,34	0,4
v	m/s	0	1,66	1,66	1,66	1,66	0	0	0
a	m/s²	11,86	11,86	0	0	–11,86	–11,86	0	0

1) t_{acc}: acceleration time
2) t_{work}: machining time
3) t_{dec}: deceleration time
4) t_{stop}: pause time

10.4 Acceleration distance

The acceleration distance s_{acc} is equal to the braking distance s_{dec} and is calculated using the acceleration a_{acc} = 11,86 m/s² and the time t_{acc} = 0,14 s.

f 22

$$s_{acc} = \frac{1}{2} \cdot a_{acc} \cdot t_{acc}^2$$

a_{acc}	m/s²	Acceleration
s_{acc}	m	Acceleration distance
t_{acc}	s	Acceleration time

f 23

$$s_{acc} = \frac{1}{2} \cdot 11,86 \cdot 0,14^2 = 0,116\ m$$

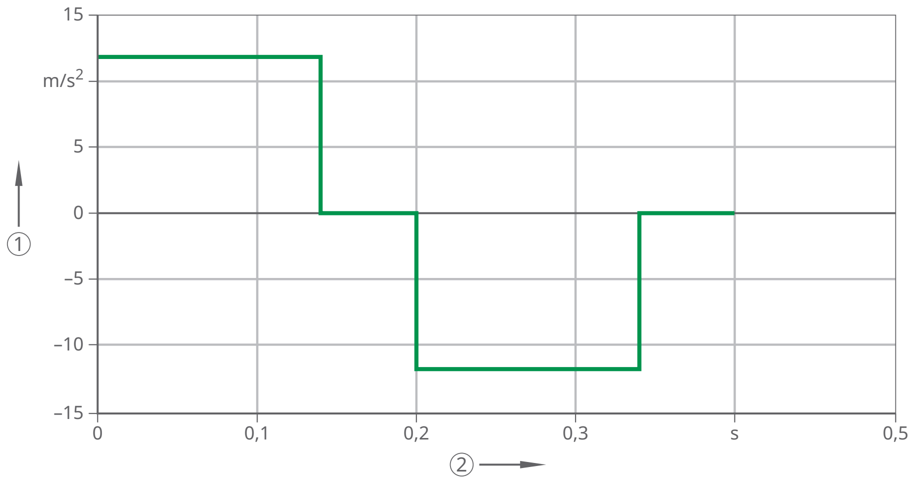
The table is extended to include the now known positions:

15 Motion cycle

Symbol	Unit	Step 1 (acc)		Step 2 (work)		Step 3 (dec)		Step 4 (stop)	
		Start	End	Start	End	Start	End	Start	End
Δt	s	–	0,14 [1)]	–	0,06 [2)]	–	0,14 [3)]	–	0,06 [4)]
t	s	0	0,14	0,14	0,2	0,2	0,34	0,34	0,4
v	m/s	0	1,66	1,66	1,66	1,66	0	0	0
a	m/s²	11,86	11,86	0	0	–11,86	–11,86	0	0
Position	m	0	0,116	0,116	0,216	0,216	0,332	0,332	0,332

1) t_{acc}: acceleration time
2) t_{work}: machining time
3) t_{dec}: deceleration time
4) t_{stop}: pause time

29 Acceleration distance



1	Acceleration	2	Time

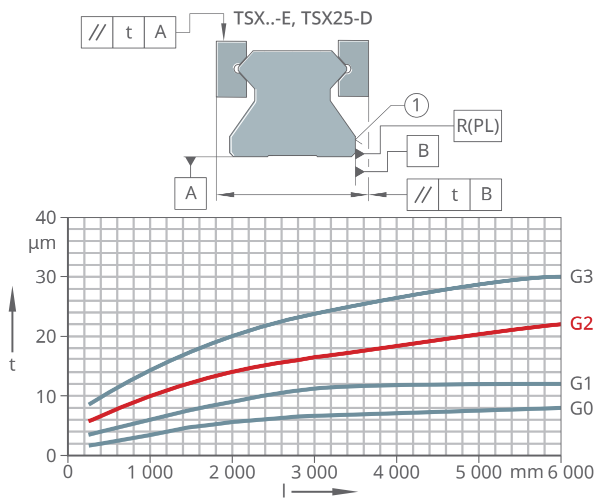
10

10.5 Guidance, mass and friction

A guidance system is required to maintain a constant air gap between the primary part and the secondary part. A suitable linear guidance system is selected in accordance with the application requirements. In particular, the accuracy class and sealing of the carriages influence the resulting displacement force and breakaway force. The expected travel velocities, acceleration and the attraction force between the primary part and the secondary part must also be taken into account.

Linear recirculating roller guidance systems are highly suitable for direct drive grinding axes. For this example, a combination of 4 RUE25-E-L carriages on 2 TSX25-D guideways is selected. This combination enables parallelism tolerances of 4 μm for the G0 design, 6 μm for the G1 design and 10 μm for the G2 design. Friction values and breakaway values depend on the accuracy class and type of guidance system.

30 Accuracy classes and parallelism tolerances of guideways



The required stroke (s_{acc} + s_{work} + s_{dec}) amounts to 332 mm. In practice, various components are machined on the machine. Therefore, a machine with a stroke of 600 mm is used.

The guideway length is the sum of the stroke of 600 mm + an assumed carriage spacing of 300 mm. In the example, the length of the guideway is therefore assumed to be 900 mm.

Further information

PF 1 | Monorail Guidance Systems |
This publication is available from Schaeffler.

10.5.1 Friction

The friction forces and breakaway forces result from the accuracy class and are highly dependent on the selected carriages and guideways. When designing the linear guidance system, the expected displacement forces were assumed to be F_{ca} = 13 N per carriage:

ƒ24

$$F_{RV} = n \cdot F_{ca}$$

F_{RV}	N	Carriage displacement force
F_{ca}	N	Displacement force per carriage
n	–	Number of carriages

ƒ25

$$F_{RV} = 4 \cdot 13 = 52 \text{ N}$$

In addition to this value, the breakaway force F_L must also be considered, which can amount to up to 40 % of the displacement force.

ƒ26

$$F_L = 0{,}4 \cdot F_{RV}$$

F_L	N	Breakaway force
F_{RV}	N	Carriage displacement force

ƒ27

$$F_L = 0{,}4 \cdot 52 = 20{,}8 \text{ N}$$

The breakaway force only occurs briefly when the axis starts to move.

10.5.2 Mass

The workpiece, workpiece carrier with 4 carriages and cable drag chain have a mass of approximately 200 kg. In the first step, the motor mass is determined by selecting a medium-sized motor that fits into the design. For the initial calculation, a motor mass of 20 kg is used. After the final selection, the calculation is repeated using the actual mass of the motor to be used. To simplify the example, the masses of components such as bellows or telescopic covers and the coolant within the motor have been neglected.

ƒ28

$$m = m_P + m_{part}$$

m	kg	Mass to be moved
m_P	kg	Mass of primary part
m_{part}	kg	Mass of workpiece, workpiece carrier, carriage and cable drag chain

ƒ29

$$m = 20 + 200 = 220\ \text{kg}$$

10.6 Forces during acceleration

The acceleration force F_{acc} can be calculated using the mass ➤46 | 10.5.2 and the required acceleration ➤44 | ƒ21:

ƒ30

$$F_{acc} = m \cdot a_{acc}$$

a_{acc}	m/s²	Acceleration
F_{acc}	N	Acceleration force, without friction
m	kg	Mass to be moved

ƒ31

$$F_{acc} = 220 \cdot 11{,}86 = 2609\ \text{N}$$

The total force to be provided by the motor during acceleration, $F_{acc\ tot}$, consists of the acceleration force F_{acc} required for motion, the carriage displacement force F_{RV} and the breakaway force F_L:

ƒ32

$$F_{acc\ tot} = F_{acc} + F_{RV} + F_L$$

F_{acc}	N	Acceleration force, without friction
$F_{acc\ tot}$	N	Acceleration force, incl. friction
F_L	N	Breakaway force
F_{RV}	N	Carriage displacement force

ƒ33

$$F_{acc\ tot} = 2609 + 52 + 20{,}8 = 2682\ \text{N}$$

10.7 Forces during machining

During machining, the acceleration is 0 m/s². No force is required for acceleration in this step. Only the carriage displacement force F_{RV} and the machining force F_{grind} act.

ƒ34

$$F_{work} = F_{RV} + F_{grind}$$

F_{grind}	N	Machining force
F_{RV}	N	Carriage displacement force
F_{work}	N	Force at constant velocity

ƒ35

$$F_{work} = 52 + 20 = 72\ \text{N}$$

10.8 Forces during deceleration

The force acting during deceleration, F_{dec}, consists of the acceleration force F_{acc} and the carriage displacement force F_{RV}. The friction force supports deceleration.

ƒ36

$$F_{dec} = F_{acc} - F_{RV}$$

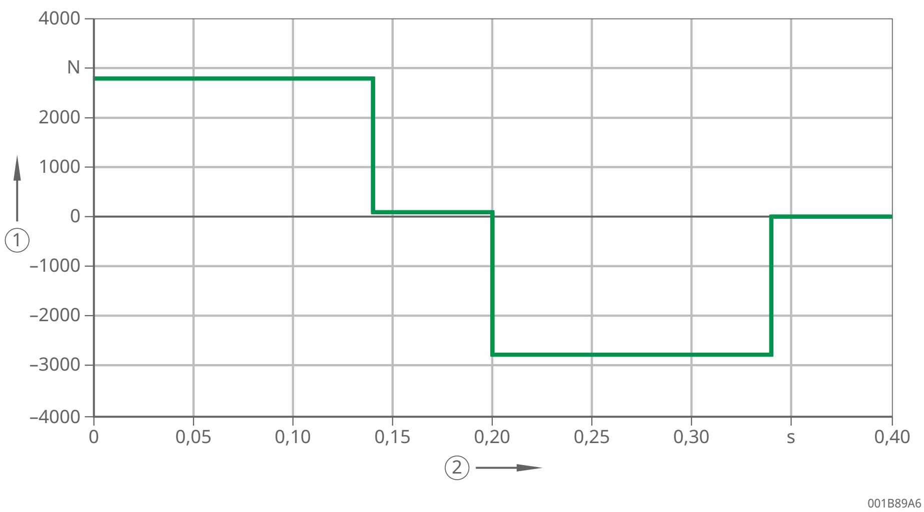
F_{acc}	N	Acceleration force, without friction
F_{dec}	N	Braking force
F_{RV}	N	Carriage displacement force

ƒ37

$$F_{dec} = 2609 - 52 = 2557\ \text{N}$$

It is recommended to represent the force profile graphically in order to identify any critical points.

31 Time profile of the total force



1	Time	2	Total force

The table is extended to include the now known total force profile:

16 Motion cycle

Symbol	Unit	Step 1 (acc)		Step 2 (work)		Step 3 (dec)		Step 4 (stop)	
		Start	End	Start	End	Start	End	Start	End
Δt	s	–	0,14 [1)]	–	0,06 [2)]	–	0,14 [3)]	–	0,06 [4)]
t	s	0	0,14	0,14	0,2	0,2	0,34	0,34	0,4
v	m/s	0	1,66	1,66	1,66	1,66	0	0	0
a	m/s^2	11,86	11,86	0	0	–11,86	–11,86	0	0
Position	m	0	0,116	0,116	0,216	0,216	0,332	0,332	0,332
F_{tot}	N	2682	2682	72	72	–2557	–2557	0	0

1) t_{acc}: acceleration time

2) t_{work}: machining time

3) t_{dec}: deceleration time

4) t_{stop}: pause time

10.9 Safety factor

Inaccuracies in the initial estimation, as well as electrical and non-linear effects, require the use of a safety factor when dynamically designing a linear motor. The safety factor also provides a force reserve to compensate for unforeseen opposing forces and malfunctions.

For motor selection based on effective force, a safety factor of SF_{eff} = 1,25 is used.

38

$$F_{safe\ eff} = F_{eff} \cdot SF_{eff} < F_{cw}$$

F_{cw}	N	Continuous force, cooled
F_{eff}	N	Effective force
$F_{safe\ eff}$	N	Effective force, incl. safety factor
SF_{eff}	–	Safety factor for effective force evaluation

For motor selection based on peak force, a safety factor of SF_{acc} = 1,4 is used.

39

$$F_{safe\ acc} = F_{acc\ tot} \cdot SF_{acc} < F_p$$

$F_{acc\ tot}$	N	Acceleration force, incl. friction
F_p	N	Peak force
$F_{safe\ acc}$	N	Acceleration force, incl. friction and safety factor
SF_{acc}	–	Safety factor for peak force evaluation

These two safety factors take into account the effects explained below:

- **non-linear effects in the force-current characteristic curve**
  The effective force F_{eff} required for motor selection applies only within the linear range of the motor ➤14 | 4.4. In the non-linear range, more current is required to generate a force. The value of the force constant k_f decreases. The generated power loss increases quadratically. SF_{acc} limits the influence of saturation and SF_{eff} takes saturation into account in the effective force calculation.
- **influence of motor inductance and electrical time constant**
  In a dynamic calculation without jerk limitation, an infinitely fast increase in acceleration is assumed. In reality, however, motor inductance and the electrical time constant delay the rate of current increase and thus the change in motor force. Typical values are 15 ms to 20 ms per positioning operation.
  - **consideration using SF_{acc}**
    This effect can be taken into account by using the safety factor SF_{acc}. This provides the motor with a higher force reserve to compensate for time delays by means of higher acceleration.
  - **consideration using time offset**
    Alternatively, the electrical time constant can be subtracted for each positioning operation. The shorter the positioning operations, the greater the influence of the electrical time constant.
- **tolerances and manufacturing-related variations**
  Tolerance range of the data sheet values: ±10 %.

! If the safety factor SF_{acc} is reduced, the safety factor SF_{eff} must be increased.

No safety factor is required for the maximum velocity v_{work}, as applying one would lead to significant oversizing. A safety factor for velocity is only required for frequency converters with an unstabilised DC link voltage ➤13 | 4.3. In this example of motor selection, a frequency converter with a stabilised DC link voltage is used.

10.10 Required effective force

The effective force represents a complex cycle as a single value. This value corresponds to a duty cycle of 100 % and generates the same amount of heat in the linear range as the actual cycle. The effective force is a value for motor selection and is calculated as follows:

ƒ40

$$F_{eff} = \sqrt{\frac{1}{t_{tot}}\left(F_{acc\ tot}^2 \cdot t_{acc} + F_{work}^2 \cdot t_{work} + F_{dec}^2 \cdot t_{dec}\right)}$$

$F_{acc\ tot}$	N	Acceleration force, incl. friction
F_{dec}	N	Braking force
F_{eff}	N	Effective force
F_{work}	N	Force at constant velocity
t_{acc}	s	Acceleration time
t_{dec}	s	Deceleration time
t_{tot}	s	Cycle time
t_{work}	s	Machining time

ƒ41

$$F_{eff} = \sqrt{\frac{1}{0{,}4}\left(2682^2 \cdot 0{,}14 + 72^2 \cdot 0{,}06 + \left(-2557\right)^2 \cdot 0{,}14\right)} = 2192\ \text{N}$$

By taking into account the safety factor SF_{eff} ➤49 | ƒ38, the force $F_{safe\ eff}$ required for motor selection is obtained.

ƒ42

$$F_{safe\ eff} = F_{eff} \cdot SF_{eff}$$

F_{eff}	N	Effective force
$F_{safe\ eff}$	N	Effective force, incl. safety factor
SF_{eff}	–	Safety factor for effective force evaluation

ƒ43

$$F_{safe\ eff} = 2192 \cdot 1{,}25 = 2740\ \text{N}$$

10.11 Required peak force

ƒ44

$$F_{safe\ acc} = F_{acc\ tot} \cdot SF_{acc}$$

$F_{acc\ tot}$	N	Acceleration force, incl. friction
$F_{safe\ acc}$	N	Acceleration force, incl. friction and safety factor
SF_{acc}	–	Safety factor for peak force evaluation

ƒ45

$$F_{safe\ acc} = 2682 \cdot 1{,}4 = 3755\ \text{N}$$

10.12 Motor selection

The following criteria determine the motor selection:

- **Criterion 1: peak force F_p**
  The force required for acceleration, $F_{safe\ acc}$, of 3755 N, must be less than the F_p value of the motor ➤49|ƒ39.
- **Criterion 2: continuous force F_{cw}**
  The effective force including safety factor, $F_{safe\ eff}$, of 2740 N, must be less than the F_{cw} value of the motor ➤49|ƒ38.
- **Criterion 3: travel velocity at the operating point**
  The maximum velocity v_{work} = 1,66 m/s must be achievable at the corresponding force $F_{acc\ tot}$ = 2682 N and the corresponding DC link voltage U_{DCL}.
  First, the DC link voltage is checked and the corresponding limiting velocity is determined. The following two options are then evaluated:
  Case 1: $F_{acc\ tot} > F_{cw}$
  It is checked whether v_{work} is less than v_{lp}.
  Case 2: $F_{acc\ tot} < F_{cw}$
  It is checked whether v_{work} is less than v_{lw}.

If the evaluation of case 1 or case 2 is not successful, the operating point $F_{acc\ tot}$ = 2682 N at v_{work} can be verified using the force-velocity characteristic curve at the corresponding DC link voltage.

In the present case, a frequency converter with a stabilised DC link voltage of U_{DCL} = 600 V is used. Therefore, no safety margin is required, and the values v_{lp600} and v_{lw600} apply.

The following motors meet the requirements:

17 Motors

Motor	Peak force F_p [1]	Continuous force F_{cw} [2]	Power loss P_{lw} [3]	Motor constant k_m	Limiting velocity v_{lp600} [4]	Limiting velocity v_{lw600}
	N	N	W	N/√W	m/s	m/s
L7-3P-500-100-Z2.8H	6078	2700	1556	81	1,9	4,48
L7-3P-350-150-Z1.9H	6078	2760	1442	86	1,36	3,08

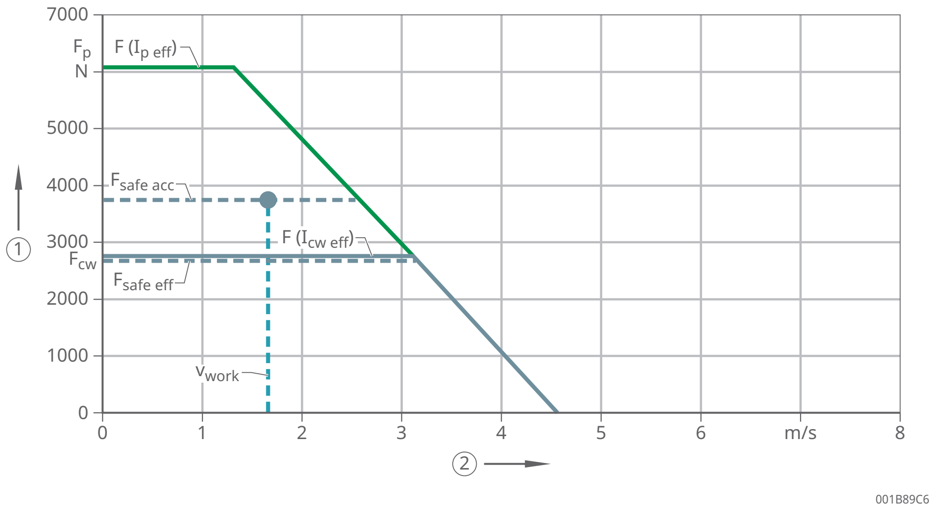
1) at $I_{p\ eff}$
2) at $I_{cw\ eff}$
3) at F_{cw}
4) at $I_{p\ eff}$ and U_{DCL}

Both motors meet criterion 1 (➤49|ƒ39).

The motor L7-3P-350-150-Z1.9H meets criterion 2 (➤49|ƒ38), whereas the motor L7-3P-500-100-Z2.8H narrowly fails to meet this criterion (➤49|ƒ38) by approximately 1,4 %.

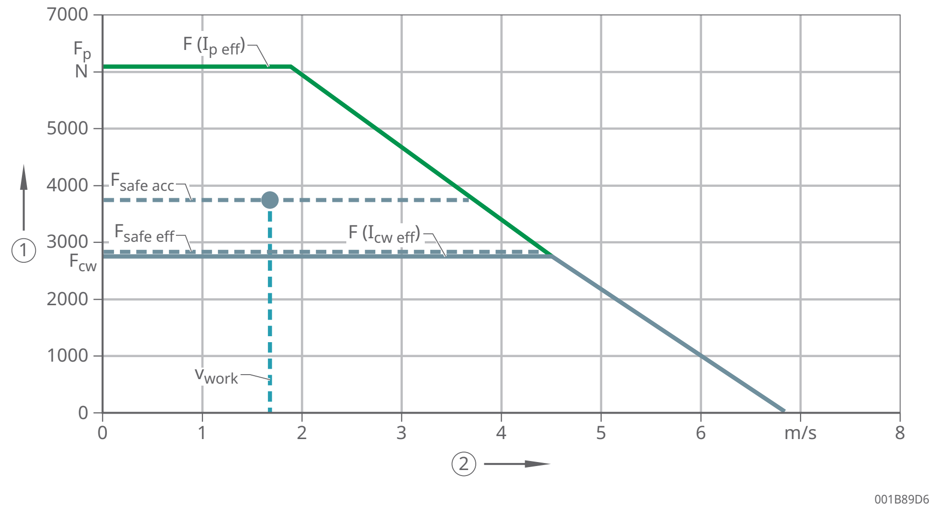
Both motors meet criterion 3, case 2 ($F_{acc\ tot} < F_{cw}$ & $v_{work} < v_{lw600}$). For better clarity, a graphical evaluation is provided for both motors:

32 Force-velocity characteristic curve – L7-3P-350-150-Z1.9H at U_{DCL} = 600 V, $I_{cw\ eff}$ = 17,5 A



1 Force F	2 Velocity v

33 Force-velocity characteristic curve – L7-3P-500-100-Z2.8H at U_{DCL} = 600 V, $I_{cw\ eff}$ = 25,7 A



1 Force F	2 Velocity v

The motor L7-3P-350-150-Z1.9H is selected:

It has a lower current requirement $I_{cw\ eff}$, is shorter, and has lower power loss P_{lw} than the L7-3P-500-100-Z2.8H. This has a positive effect on the installation space, the selection of the frequency converter and the design of the guidance systems.

11 Ordering designation

34 L7 series, primary part

L7------ | 3P | 0350 | 100 | ZX.XH | P | O | M | C | A | 2.0 | PRIM | N-- | Y

Short designation, motor

L7	Linear motor series

Number of motor phases

3P	3-phase

Design length

0350	350 mm
0500	500 mm
0650	650 mm

Design width

100	100 mm
150	150 mm
200	200 mm
300	300 mm

Winding version

ZX.XH	According to catalogue/data sheet

Temperature monitoring

P	1 Pt1000 and 3 PTC
T	3 Pt1000 and 3 PTC

Commutation type

O	Without sensors, measuring system commutated

Design variant

M	Standard installation components

Connection type

C	4GX cable and separate sensor cable

Connection direction

A	Straight, in direction of motion

Cable length

2.0	Cable length in m

Motor part

PRIM	Primary part

Blank

Standard item (defined by Schaeffler Industrial Drives)

Y	Standard (winding version, customer delivery drawing, connection type and connection direction, temperature monitoring)
N	Non-standard

001DF22E

35 L7 series, secondary part

L7------	3P	0184	100	N----	N	N	M	N-	N.N	SEK-	N--	Y

Short designation, motor

L7	Linear motor series

Number of motor phases

3P	3-phase

Design length

0184	184 mm

Design width

100	100 mm
150	150 mm
200	200 mm
300	300 mm

Blank

Blank

Blank

Design variant

M	Standard, without casting
P	Encapsulated, with casting

Blank

Blank

Motor part

SEK	Secondary part

Magnet configuration

N	Standard

Standard item (defined by Schaeffler Industrial Drives)

Y	Standard
N	Non-standard

001DF23E

36 L7 series, secondary part accessories: cooling profile

L7------	N-	0164	N--	N----	N	N	M	S1	-	N.N	CP--	N--	Y

Short designation, motor
L7 Linear motor series

Blank

Design length
0164 Required length in mm

Blank

Blank

Blank

Blank

Connection type
M Standard, coupling

Profile version
S1 Single-circuit, suitable for design widths 100 mm and 150 mm
D1 Dual-circuit, suitable for design width 200 mm
D2 Dual-circuit, suitable for design width 300 mm

Blank

Blank

Component
CP Cooling profile

Blank

Standard item (defined by Schaeffler Industrial Drives)
Y Drawing is standard
N Non-standard

001DF25A

The length of the cooling profiles is calculated using a formula ➤60 | 11.2.

37 L7 series, secondary part accessories: secondary part cover

L7------	N-	1960	100	N----	N	N	M	N-	N.N	COV-	N--	Y

Short designation, motor
L7 Linear motor series

Blank

Design length
1960 Required length in mm, max. length = 5000 mm

Design width
100 100 mm
150 150 mm
200 200 mm
300 300 mm

Blank

Blank

Blank

Design variant
M Standard, continuous cover strip

Blank

Blank

Component
COV Secondary part cover

Blank

Standard item (defined by Schaeffler Industrial Drives)
Y Drawing is standard
N Non-standard

001DF26A

The length of the required secondary part cover is calculated using a formula ➤59 | 11.1.

11

38 L7 series, secondary part accessories: end pieces

L7------ | N- | N--- | 100 | N---- | N | N | MC | N | N.N | END- | N-- | Y

Short designation, motor

L7	Linear motor series

Blank

Blank

Design width

100	100 mm
150	150 mm
200	200 mm
300	300 mm

Blank

Blank

Blank

Design variant

MC	Only for fastening a continuous cover strip
KM	Only for connection of cooling profiles
KC	For connection of cooling profiles and fastening of a continuous cover strip

Blank

Blank

Component

END	End piece

Blank

Standard item (defined by Schaeffler Industrial Drives)

Y	Drawing is standard
N	Non-standard

001DF27A

11.1 Length of the cover strip

The required cover strip length is calculated using the following formula:

ƒ46

$$L_{cs} = (N_S \cdot 184) + 120$$

L_{CS}	mm	Length of the cover strip
N_S	-	Number of secondary parts

18 Length of the cover strip

Number of secondary parts N_S	Length of the cover strip	Product key
–	mm	–
1	304	0304
2	488	0488
3	672	0672
4	856	0856
5	1040	1040
6	1224	1224
7	1408	1408
8	1592	1592
9	1776	1776
10	1960	1960
11	2144	2144
12	2328	2328
13	2512	2512
14	2696	2696
15	2880	2880
16	3064	3064
17	3248	3248
18	3432	3432
19	3616	3616
20	3800	3800
21	3984	3984
22	4168	4168
23	4352	4352
24	4536	4536
25	4720	4720
26	4904	4904
x [1]	5000	5000

[1] x: Standard roll for cutting to length by customer, preferred product

11

11.2 Cooling profile length

The length of the cooling profiles is calculated using the following formula:

ƒ47

$$L_{CP} = \left(N_S \cdot 184\right) - 20$$

L_{CP}	mm	Length of cooling profiles
N_S	-	Number of secondary parts

19 Cooling profile length

Number of secondary parts N_S	Required cooling profile length	Product key
–	mm	–
1	164	0164
2	348	0348
3	532	0532
4	716	0716
5	900	0900
6	1084	1084
7	1268	1268
8	1452	1452
9	1636	1636
10	1820	1820
11	2004	2004
12	2188	2188
13	2372	2372
14	2556	2556
15	2740	2740
16	2924	2924
x [1)]	3000	3000

1) x: Standard profile sections for cutting to length by customer, preferred product

11

12 Technical data

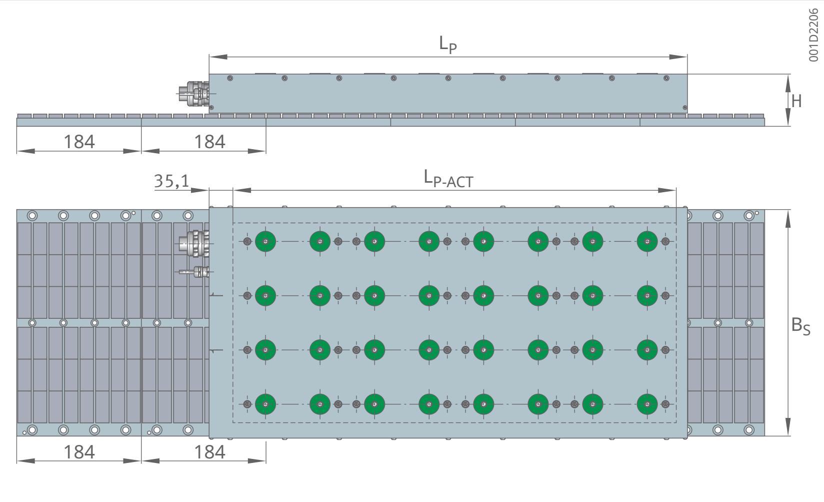
12.1 Explanations

$2\tau_p$	–	Pole pair width
B_S	mm	Width of the secondary part
dV/dt	l/min	Volume flow
F_a	N	Attraction force
F_c	N	Continuous force, not cooled
F_{cog}	N	Cogging force at I = 0
F_{cw}	N	Continuous force, cooled
F_p	N	Peak force
F_{sw}	N	Stall force, cooled
F_u	N	Ultimate force
H	mm	Height without secondary part cooling
$I_{c\ eff}$	A	Effective continuous current, not cooled
$I_{cw\ eff}$	A	Effective continuous current, cooled
$I_{p\ eff}$	A	Effective peak current
$I_{sw\ eff}$	A	Effective stall current, cooled
$I_{u\ eff}$	A	Effective ultimate current
k_f	N/A	Force constant
k_m	N/√W	Motor constant, linear motors
$k_{\hat{u}}$	V/(m/s)	Back EMF constant, phase to phase
L	mH	Inductance, phase to phase
L_{CP}	mm	Length of cooling profiles
L_P	mm	Length of the primary part
$L_{P\text{-}ACT}$	mm	Magnetically active length
m_{EP1}	kg	Mass of the secondary part with cooling and cover strip
m_{EP2}	kg	Mass of the secondary part, with cover strip only
m_{EP3}	kg	Mass of the secondary part, with cooling only (kg)
m_P	kg	Mass of primary part
m_S	kg	Mass of the secondary part, version M
m_{SP}	kg	Mass of the secondary part, version P
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts
P_{lc}	W	Power loss at F_c
P_{lp}	W	Power loss at F_p
P_{lw}	W	Power loss at F_{cw}
R_{20}	Ω	Electrical resistance at +20 °C, phase to phase
U_{DCL}	V	DC link voltage
$v_{lp\ 300}$	m/s	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V
$v_{lp\ 600}$	m/s	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V
v_{lw300}	m/s	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V
v_{lw600}	m/s	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V
Δp	bar	Pressure drop
$\Delta\vartheta$	K	Cooling water temperature difference
ϑ_{nf}	°C	Nominal feed temperature
ϑ_{PTC}	°C	Motor temperature switch-off threshold

Tolerance range of the values: ±10 %.

Binding data and drawings are available on request. For motor design, we recommend obtaining support from our engineers.

12.2 Preliminary selection



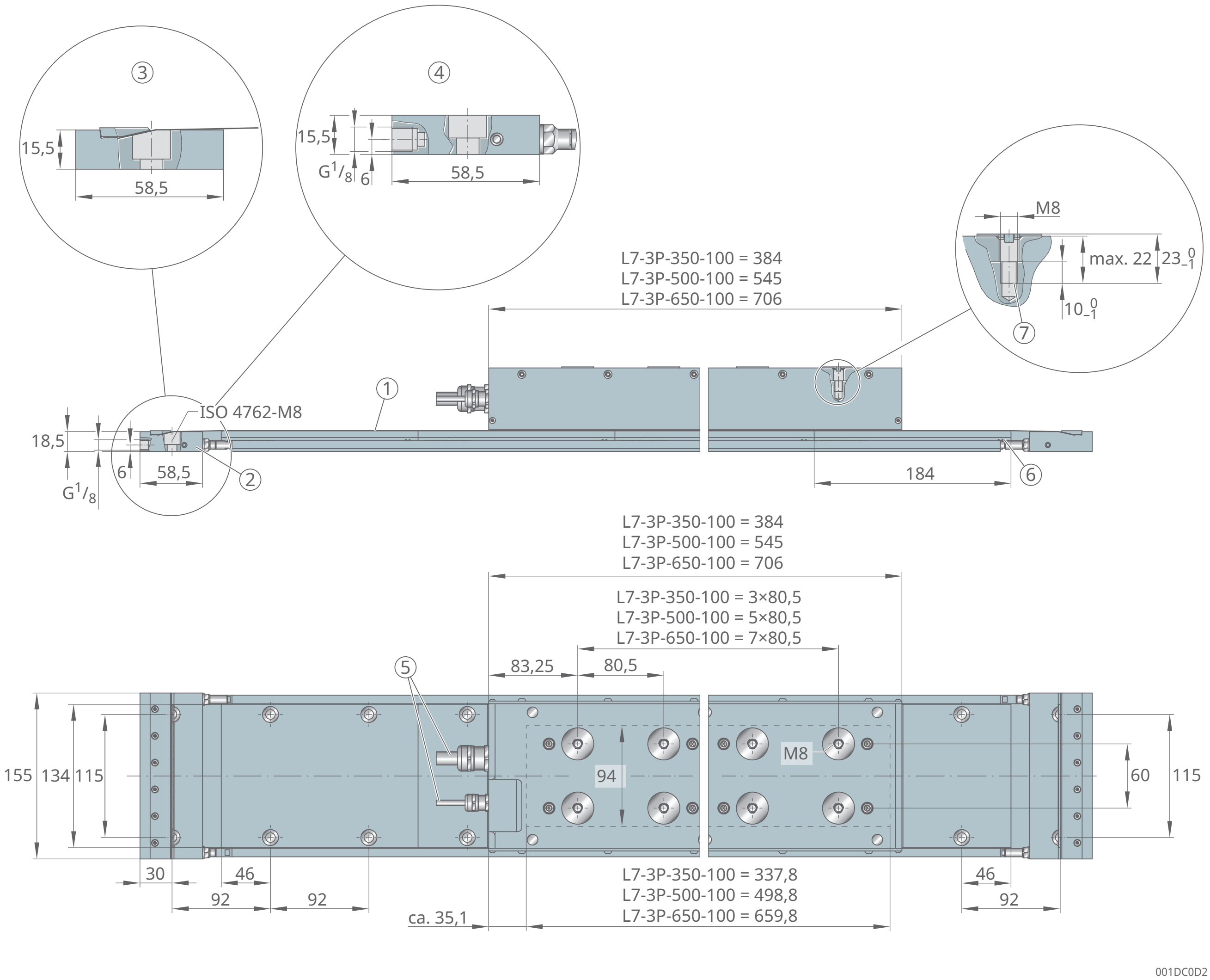
Dimensions

20 Data for preliminary selection

Size	Winding	F_p	F_{cw}	v_{lp600}	v_{lp300}	$I_{p\ eff}$	$I_{cw\ eff}$	L_P	B_S	H	L_{P-ACT}	m_P
–	–	N	N	m/s	m/s	A	A	mm	mm	mm	mm	kg
350-100	Z1.9H	4052	1813	1,95	0,82	52,5	17,3	384	134	76	337,8	15
500-100	Z2.8H	6078	2700	1,90	0,80	78,7	25,7	545	134	76	498,8	21
650-100	Z2.7H	8104	3638	1,40	0,54	79,7	26,3	706	134	76	659,8	27
350-150	Z1.9H	6078	2760	1,36	0,51	52,5	17,5	384	180	78	337,8	21
500-150	Z2.8H	9117	4111	1,36	0,51	78,7	26,1	545	180	78	498,8	30
650-150	Z2.7H	12157	5539	0,98	0,30	79,7	26,7	706	180	78	659,8	39
350-200	Z2.8H	8104	3727	1,36	0,53	72,7	24,6	384	240	76	337,8	28
500-200	Z2.8H	12157	5535	0,92	0,28	78,7	26,3	545	240	76	498,8	41
650-200	Z3.8H	16209	7385	1,20	0,44	130,5	43,7	706	240	76	659,8	53
350-300	Z2.8H	12157	5667	0,88	0,27	72,7	24,9	384	334	78	337,8	40
500-300	Z2.8H	18235	8415	0,56	0,03	78,7	26,7	545	334	78	498,8	57
650-300	Z3.8H	24313	11229	0,76	0,20	130,5	44,3	706	334	78	659,8	76

12.3 L7-3P-...-100 Geometric data

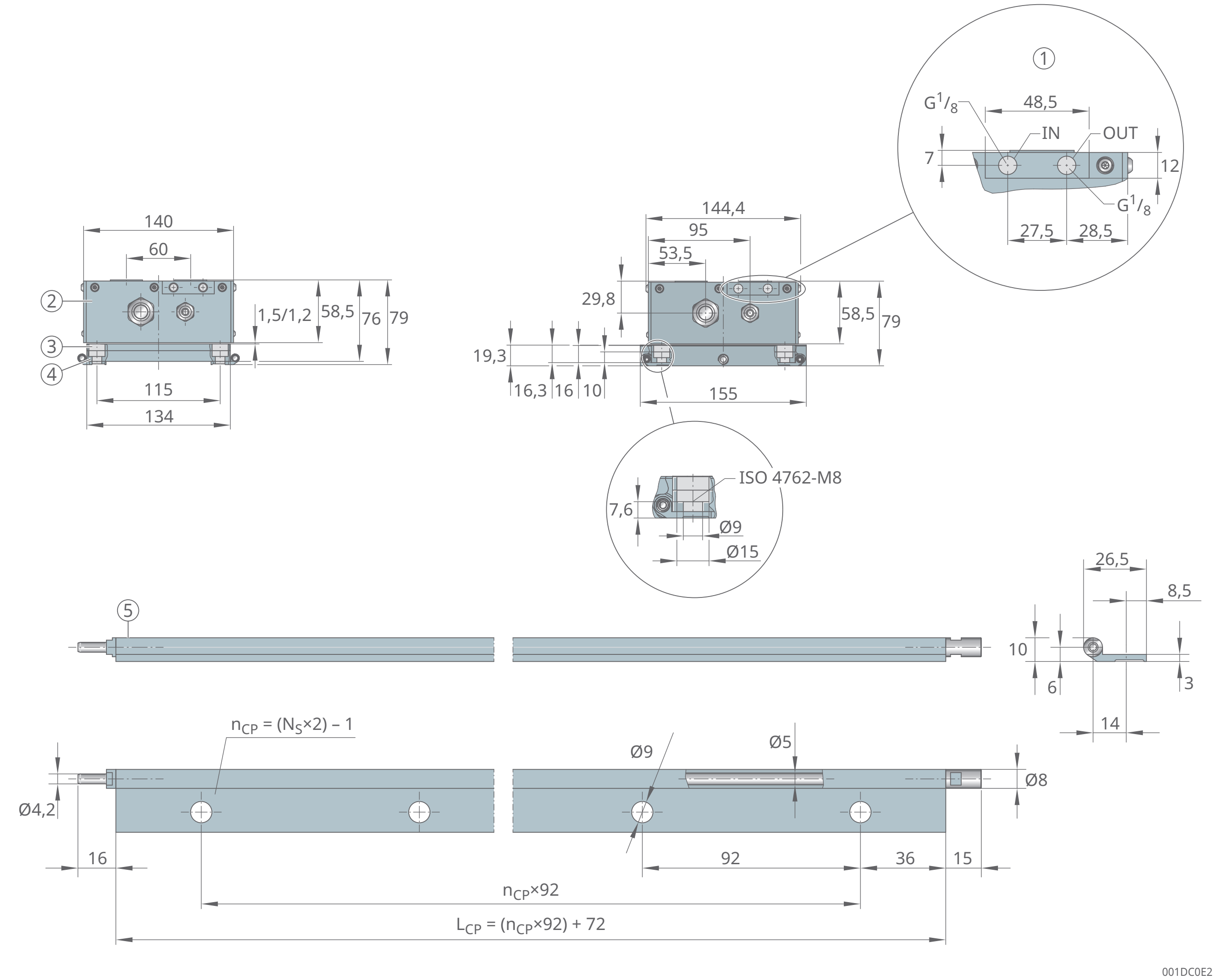
39 Geometric data



1	Optional: secondary part with cover strip	2	Optional: end piece, with cooling and cover strip
3	Optional: end piece, with cover strip only	4	Optional: end piece, with cooling only
5	Electrical connection	6	Observe the position of the N marking
7	Primary part, screw-in depth		

Size				L7-3P-350-100	L7-3P-500-100	L7-3P-650-100
Primary part		m_P	kg	15	21	27
Secondary part	Version M	m_S	kg	2,56	2,56	2,56
	Version P	m_{SP}	kg	2,64	2,64	2,64
End pieces	With cooling and cover strip	m_{EP1}	kg	0,45	0,45	0,45
	With cover strip only	m_{EP2}	kg	0,372	0,372	0,372
	With cooling only	m_{EP3}	kg	0,375	0,375	0,375

40 Geometric data



1	Connections for water cooling, inlet and outlet	2	Primary part
3	Secondary part	4	Optional: cooling profile with connector
5	Cooling profiles are available as single profiles up to a maximum length L_{CP} of 2924 mm		

L_{CP}	mm	Length of cooling profiles
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts

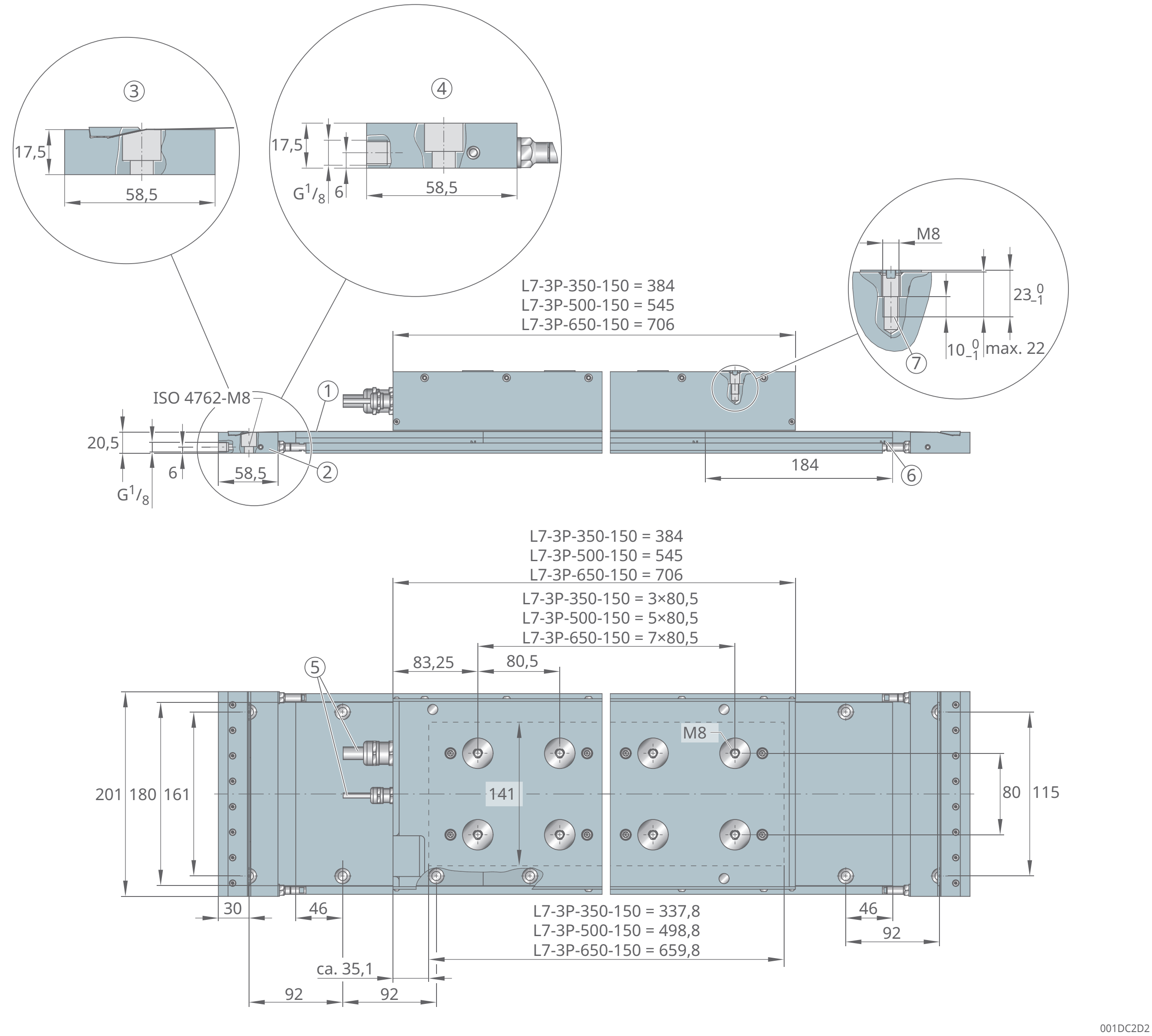
12.4 L7-3P-...-100 Performance data

Size				**350-100**
Winding version				**Z1.9H**
Forces	Ultimate force at $I_{u\ eff}$	F_u	N	4432
	Peak force at $I_{p\ eff}$	F_p	N	4052
	Continuous force, cooled, at $I_{cw\ eff}$	F_{cw}	N	1813
	Continuous force, not cooled, at $I_{c\ eff}$	F_c	N	661
	Stall force, cooled, at $I_{sw\ eff}$	F_{sw}	N	1288
	Cogging force at I = 0	F_{cog}	N	8,10
Velocities	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V	v_{lp600}	m/s	1,95
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V	v_{lw600}	m/s	4,53
	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V	v_{lp300}	m/s	0,82
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V	v_{lw300}	m/s	2,08
Currents	Effective ultimate current	$I_{u\ eff}$	A	65,6
	Effective peak current	$I_{p\ eff}$	A	52,5
	Effective continuous current, cooled	$I_{cw\ eff}$	A	17,3
	Effective continuous current, not cooled	$I_{c\ eff}$	A	6,17
	Effective stall current, cooled	$I_{sw\ eff}$	A	12,2
Power losses	Power loss at F_p	P_{lp}	W	7267
	Power loss at F_{cw}	P_{lw}	W	1052
	Power loss at F_c	P_{lc}	W	134
Electrical characteristic values	DC link voltage	U_{DCL}	V	800
	Electrical resistance, phase to phase	R_{20}	Ω	1,76
	Inductance, phase to phase	L	mH	29,69
	Back EMF constant, phase to phase	$k_{\hat{u}}$	V/(m/s)	87,7
General characteristic values	Pole pair width	$2\tau_p$	–	46
	Motor constant at +20 °C	k_m	N/√W	66,1
	Force constant	k_f	N/A	107,2
	Motor temperature switch-off threshold	ϑ_{PTC}	°C	110
	Attraction force	F_a	N	6205
Cooling conditions	Volume flow	dV/dt	l/min	4,0
	Nominal supply temperature of the cooling water	ϑ_{nf}	°C	20
	Cooling water temperature difference	$\Delta\vartheta$	K	3,8
	Pressure drop	Δp	bar	0,3

500-100	650-100
Z2.8H	**Z2.7H**
6648	8864
6078	8104
2700	3638
951	1258
1918	2584
12,16	16,21
1,90	1,40
4,48	3,34
0,80	0,54
2,06	1,51
98,4	99,7
78,7	79,7
25,7	26,3
8,87	8,91
18,2	18,6
10900	14128
1556	2059
185	236
800	800
1,17	1,48
20,39	26,51
87,7	115,5
46	46
81,0	94,9
107,2	141,2
110	110
9307	12410
4,5	5,0
20	20
5,0	5,9
0,4	0,6

12.5 L7-3P-...-150 Geometric data

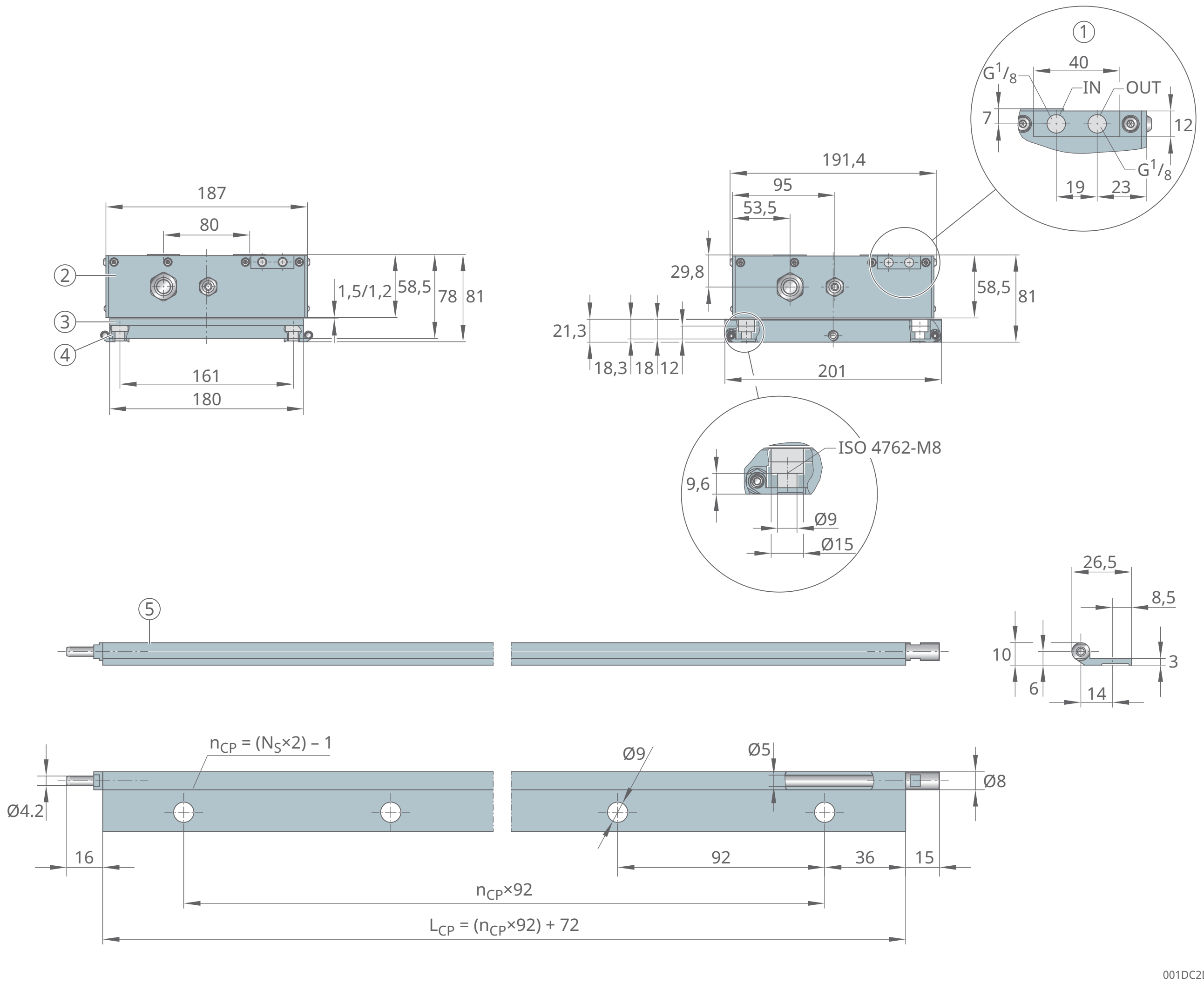
41 Geometric data



1	Optional: secondary part with cover strip	2	Optional: end piece, with cooling and cover strip
3	Optional: end piece, with cover strip only	4	Optional: end piece, with cooling only
5	Electrical connection	6	Observe the position of the N marking
7	Primary part, screw-in depth		

Size				L7-3P-350-150	L7-3P-500-150	L7-3P-650-150
Primary part		m_P	kg	21	30	39
Secondary part	Version M	m_S	kg	4,07	4,07	4,07
	Version P	m_{SP}	kg	4,16	4,16	4,16
End pieces	With cooling and cover strip	m_{EP1}	kg	0,645	0,645	0,645
	With cover strip only	m_{EP2}	kg	0,548	0,548	0,548
	With cooling only	m_{EP3}	kg	0,546	0,546	0,546

42 Geometric data



1	Connections for water cooling, inlet and outlet	2	Primary part
3	Secondary part	4	Optional: cooling profile with connector
5	Cooling profiles are available as single profiles up to a maximum length L_{CP} of 2924 mm		

L_{CP}	mm	Length of cooling profiles
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts

12.6 L7-3P-...-150 Performance data

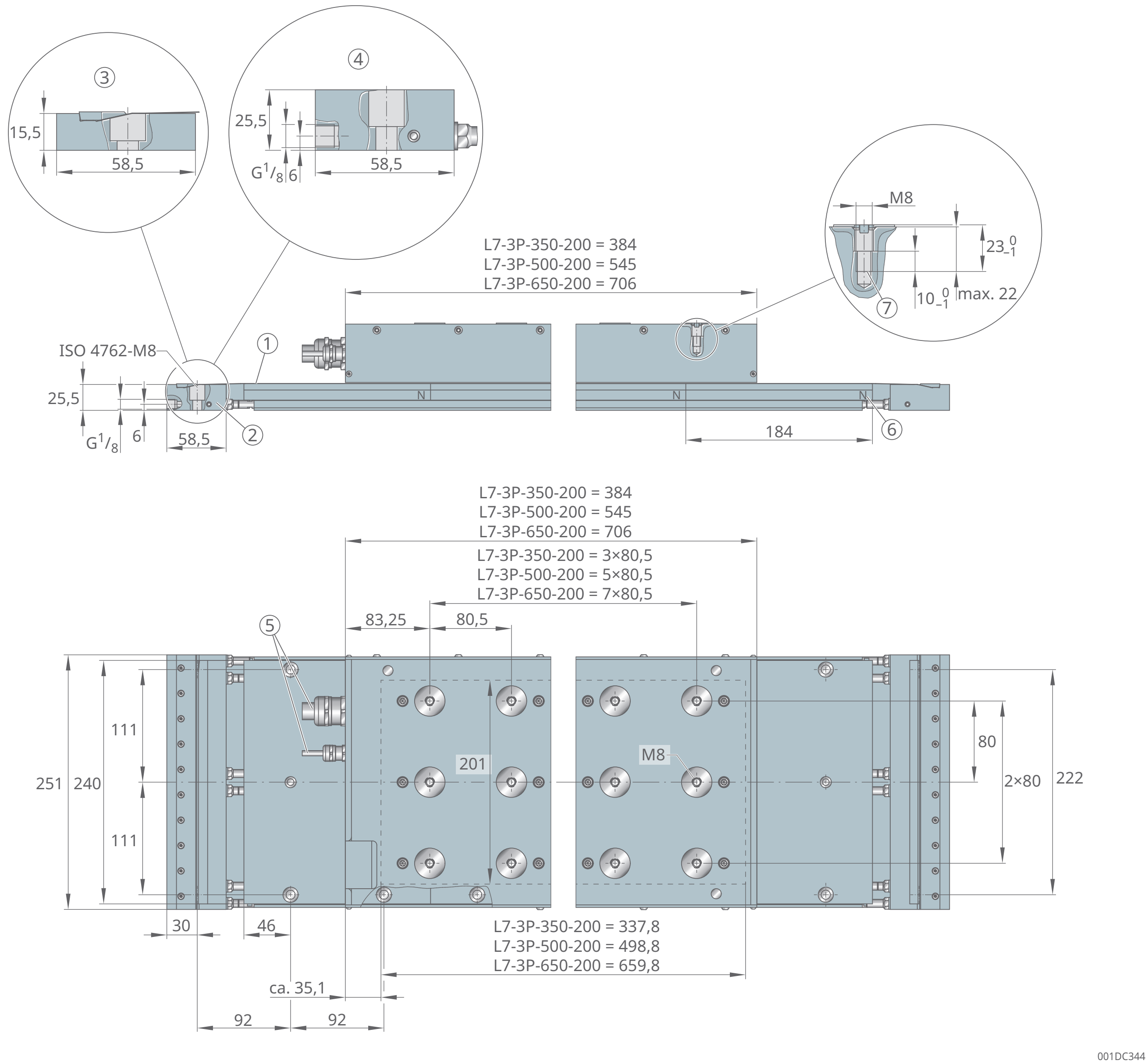
12

Size				350-150
Winding version				**Z1.9H**
Forces	Ultimate force at $I_{u\ eff}$	F_u	N	6648
	Peak force at $I_{p\ eff}$	F_p	N	6078
	Continuous force, cooled, at $I_{cw\ eff}$	F_{cw}	N	2760
	Continuous force, not cooled, at $I_{c\ eff}$	F_c	N	961
	Stall force, cooled, at $I_{sw\ eff}$	F_{sw}	N	1832
	Cogging force at I = 0	F_{cog}	N	12,16
Velocities	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V	v_{Ip600}	m/s	1,36
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V	v_{Iw600}	m/s	3,08
	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V	v_{Ip300}	m/s	0,51
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V	v_{Iw300}	m/s	1,38
Currents	Effective ultimate current	$I_{u\ eff}$	A	65,6
	Effective peak current	$I_{p\ eff}$	A	52,5
	Effective continuous current, cooled	$I_{cw\ eff}$	A	17,5
	Effective continuous current, not cooled	$I_{c\ eff}$	A	5,97
	Effective stall current, cooled	$I_{sw\ eff}$	A	11,6
Power losses	Power loss at F_p	P_{lp}	W	9663
	Power loss at F_{cw}	P_{lw}	W	1442
	Power loss at F_c	P_{lc}	W	168
Electrical characteristic values	DC link voltage	U_{DCL}	V	800
	Electrical resistance, phase to phase	R_{20}	Ω	2,34
	Inductance, phase to phase	L	mH	40,38
	Back EMF constant, phase to phase	$k_{\hat{u}}$	V/(m/s)	131,5
General characteristic values	Pole pair width	$2\tau_p$	–	46
	Motor constant at +20 °C	k_m	N/√W	86,0
	Force constant	k_f	N/A	160,8
	Motor temperature switch-off threshold	ϑ_{PTC}	°C	110
	Attraction force	F_a	N	9307
Cooling conditions	Volume flow	dV/dt	l/min	4,0
	Nominal supply temperature of the cooling water	ϑ_{nf}	°C	20
	Cooling water temperature difference	$\Delta\vartheta$	K	5,2
	Pressure drop	Δp	bar	0,5

500-150	650-150
Z2.8H	**Z2.7H**
9972	13296
9117	12157
4111	5539
1380	1824
2727	3674
18,23	24,31
1,36	0,98
3,09	2,29
0,51	0,30
1,38	0,99
98,4	99,7
78,7	79,7
26,1	26,7
8,58	8,61
17,2	17,6
14495	18788
2131	2821
231	294
800	800
1,56	1,97
26,92	35,00
131,5	173,2
46	46
105,4	123,4
160,8	211,7
110	110
13961	18615
4,5	5,0
20	20
6,8	8,1
0,8	1,2

12.7 L7-3P-...-200 Geometric data

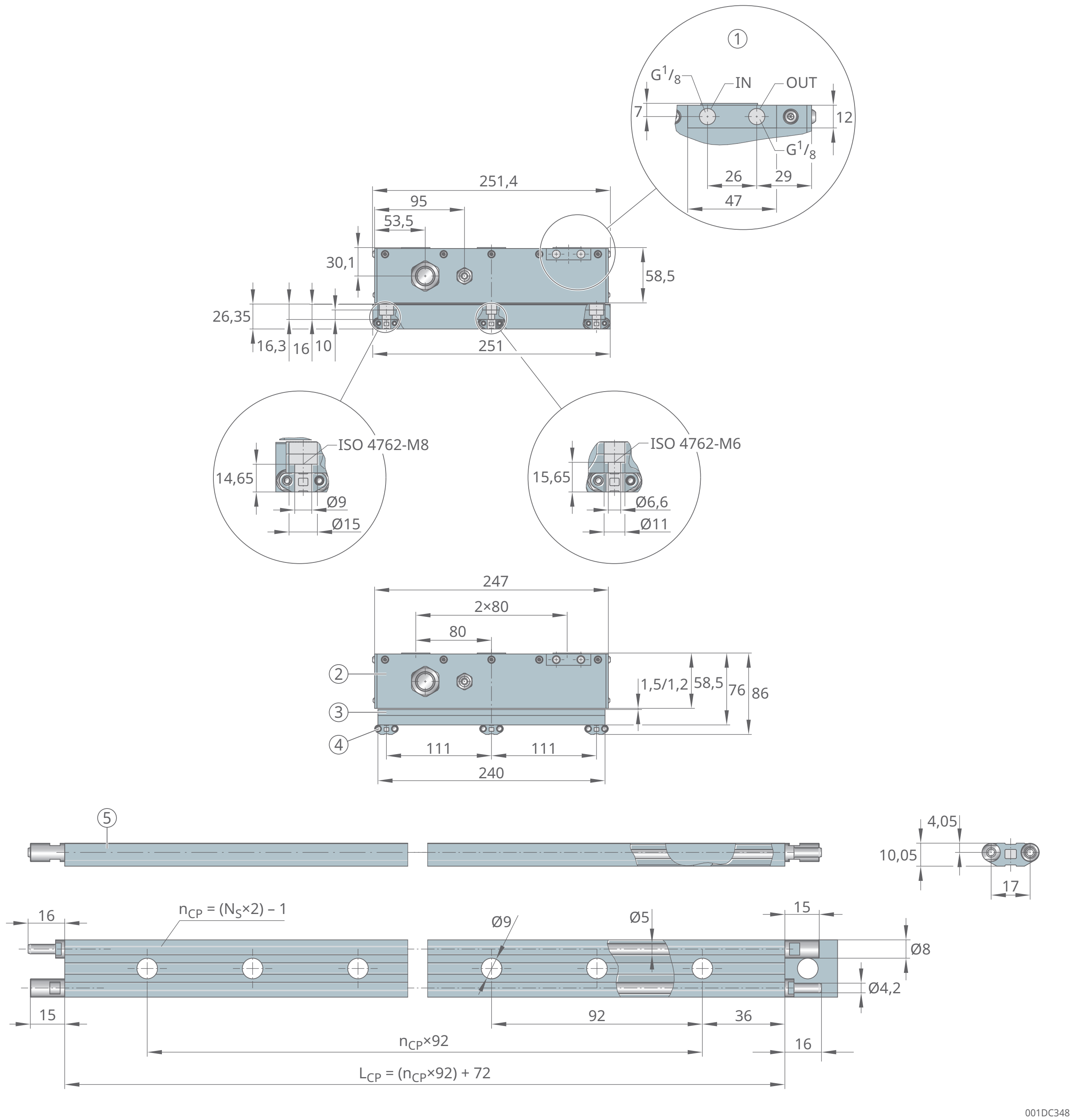
43 Geometric data



1	Optional: secondary part with cover strip	2	Optional: end piece, with cooling and cover strip
3	Optional: end piece, with cover strip only	4	Optional: end piece, with cooling only
5	Electrical connection	6	Observe the position of the N marking
7	Primary part, screw-in depth		

Size				L7-3P-350-200	L7-3P-500-200	L7-3P-650-200
Primary part		m_P	kg	28	41	53
Secondary part	Version M	m_S	kg	4,66	4,66	4,66
	Version P	m_{SP}	kg	4,85	4,85	4,85
End pieces	With cooling and cover strip	m_{EP1}	kg	1,033	1,033	1,033
	With cover strip only	m_{EP2}	kg	0,609	0,609	0,609
	With cooling only	m_{EP3}	kg	1,026	1,026	1,026

44 Geometric data



1	Connections for water cooling, inlet and outlet	2	Primary part
3	Secondary part	4	Optional: cooling profile with connector
5	Cooling profiles are available as single profiles up to a maximum length L_{CP} of 2924 mm		

L_{CP}	mm	Length of cooling profiles
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts

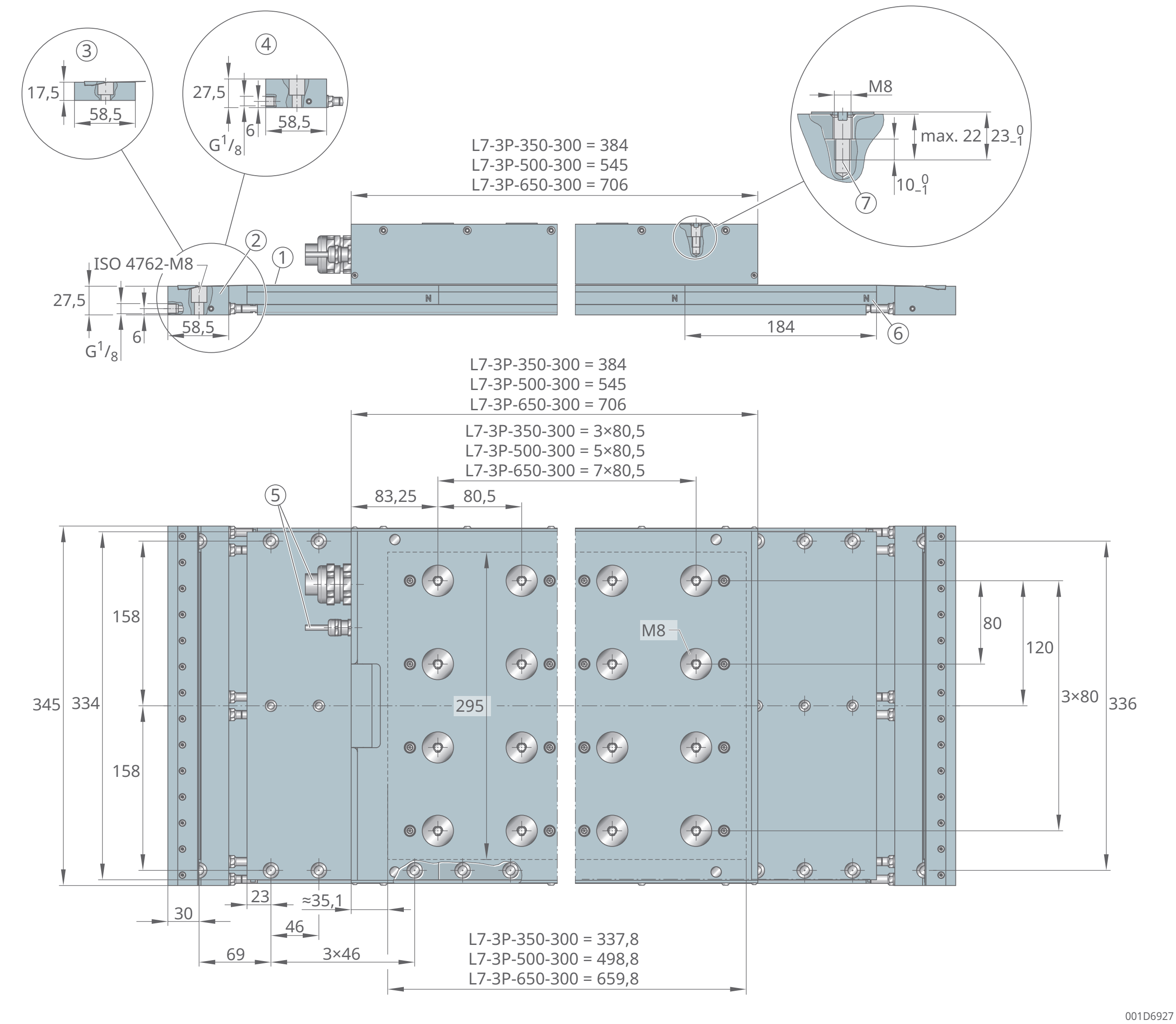
12.8 L7-3P-...-200 Performance data

Size				**350-200**
Winding version				**Z2.8H**
Forces	Ultimate force at $I_{u\ eff}$	F_u	N	8864
	Peak force at $I_{p\ eff}$	F_p	N	8104
	Continuous force, cooled, at $I_{cw\ eff}$	F_{cw}	N	3727
	Continuous force, not cooled, at $I_{c\ eff}$	F_c	N	1253
	Stall force, cooled, at $I_{sw\ eff}$	F_{sw}	N	2473
	Cogging force at I = 0	F_{cog}	N	16,21
Velocities	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V	v_{lp600}	m/s	1,36
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V	v_{lw600}	m/s	3,11
	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V	v_{lp300}	m/s	0,53
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V	v_{lw300}	m/s	1,40
Currents	Effective ultimate current	$I_{u\ eff}$	A	90,8
	Effective peak current	$I_{p\ eff}$	A	72,7
	Effective continuous current, cooled	$I_{cw\ eff}$	A	24,6
	Effective continuous current, not cooled	$I_{c\ eff}$	A	8,09
	Effective stall current, cooled	$I_{sw\ eff}$	A	16,2
Power losses	Power loss at F_p	P_{lp}	W	12648
	Power loss at F_{cw}	P_{lw}	W	1935
	Power loss at F_c	P_{lc}	W	210
Electrical characteristic values	DC link voltage	U_{DCL}	V	800
	Electrical resistance, phase to phase	R_{20}	Ω	1,60
	Inductance, phase to phase	L	mH	29,62
	Back EMF constant, phase to phase	$k_{\hat{u}}$	V/(m/s)	126,7
General characteristic values	Pole pair width	$2\tau_p$	–	46
	Motor constant at +20 °C	k_m	N/√W	100,3
	Force constant	k_f	N/A	154,9
	Motor temperature switch-off threshold	ϑ_{PTC}	°C	110
	Attraction force	F_a	N	12410
Cooling conditions	Volume flow	dV/dt	l/min	4,5
	Nominal supply temperature of the cooling water	ϑ_{nf}	°C	20
	Cooling water temperature difference	$\Delta\vartheta$	K	6,2
	Pressure drop	Δp	bar	0,7

500-200	650-200
Z2.8H	**Z3.8H**
13296	17728
12157	16209
5535	7385
1794	2346
4000	5336
24,31	32,42
0,92	1,20
2,20	2,79
0,28	0,44
0,95	1,24
98,4	163,2
78,7	130,5
26,3	43,7
8,37	13,61
19,0	31,5
19085	25222
2861	3787
289	367
800	800
2,05	0,99
37,84	18,36
175,4	141,1
46	46
122,4	142,0
214,4	172,4
110	110
18615	24820
5,5	6,0
20	20
7,5	9,1
1,4	2,0

12.9 L7-3P-...-300 Geometric data

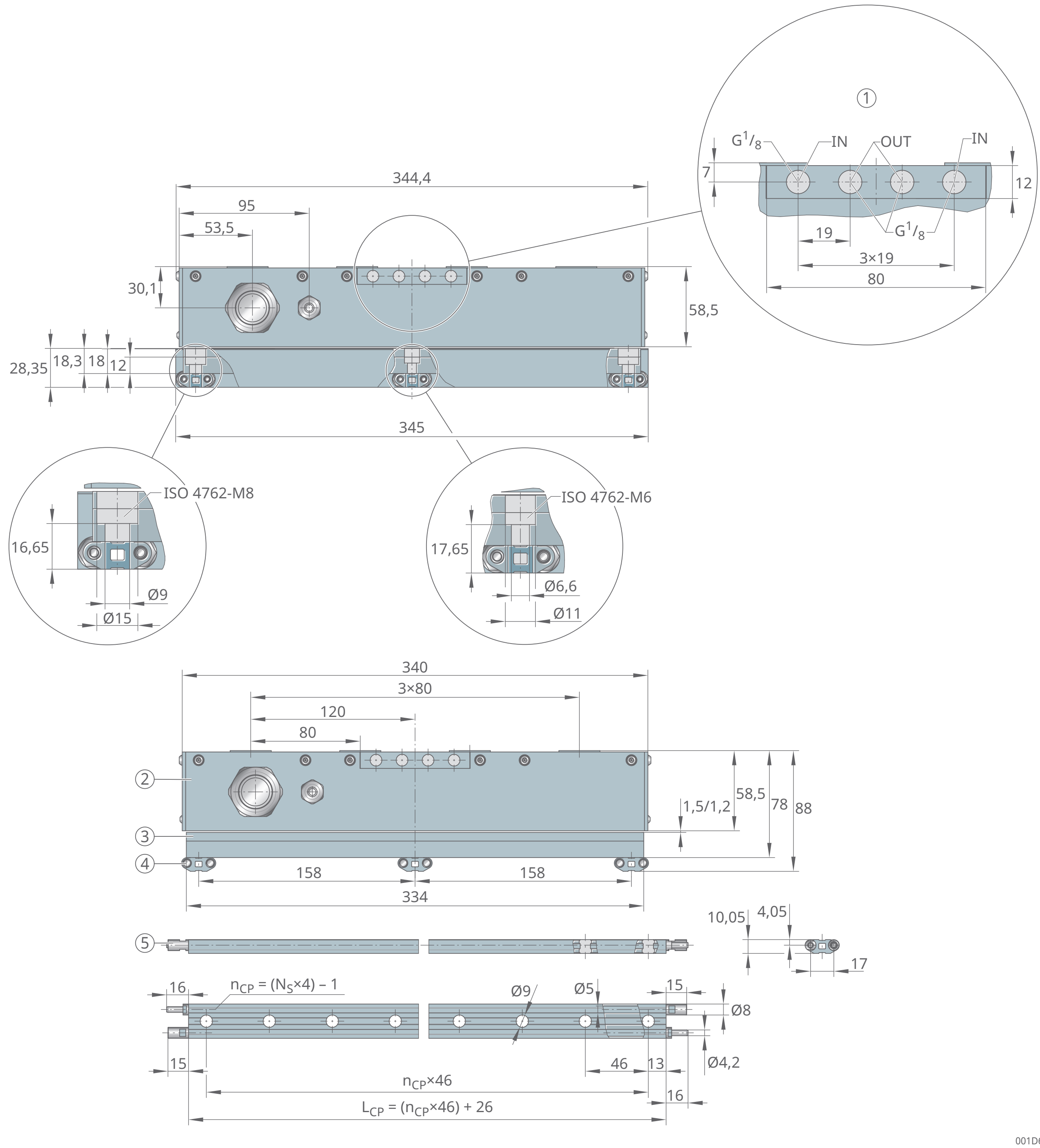
45 Geometric data



1	Optional: secondary part with cover strip	2	Optional: end piece, with cooling and cover strip
3	Optional: end piece, with cover strip only	4	Optional: end piece, with cooling only
5	Electrical connection	6	Observe the position of the N marking
7	Primary part, screw-in depth		

Size				L7-3P-350-300	L7-3P-500-300	L7-3P-650-300
Primary part		m_P	kg	40	57	76
Secondary part	Version M	m_S	kg	7,5	7,5	7,5
	Version P	m_{SP}	kg	7,7	7,7	7,7
End pieces	With cooling and cover strip	m_{EP1}	kg	1,517	1,517	1,517
	With cover strip only	m_{EP2}	kg	0,95	0,95	0,95
	With cooling only	m_{EP3}	kg	1,508	1,508	1,508

46 Geometric data



1	Connections for water cooling, inlet and outlet	2	Primary part
3	Secondary part	4	Optional: cooling profile with connector
5	Cooling profiles are available as single profiles up to a maximum length L_{CP} of 2924 mm		

L_{CP}	mm	Length of cooling profiles
n_{CP}	–	Number of hole spacings in the cooling profile
N_S	-	Number of secondary parts

12.10 L7-3P-...-300 Performance data

12

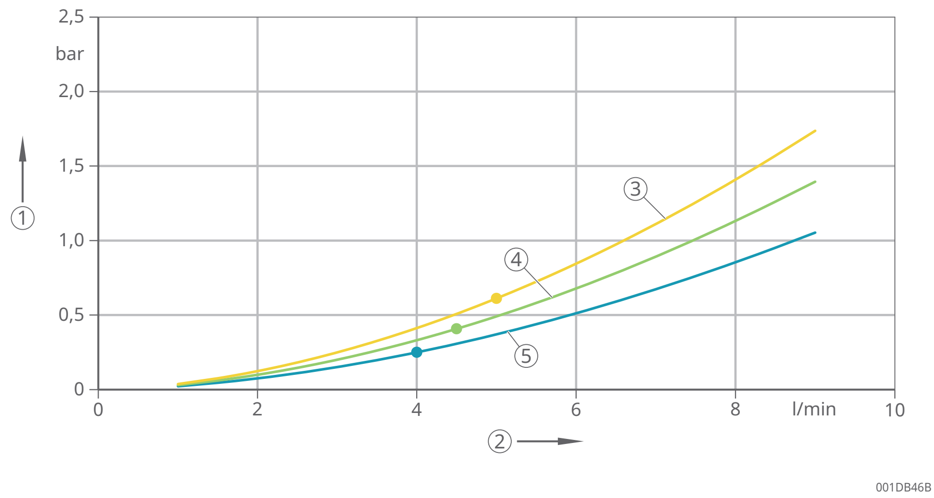
Size				**350-300**
Winding version				**Z2.8H**
Forces	Ultimate force at $I_{u\ eff}$	F_u	N	13296
	Peak force at $I_{p\ eff}$	F_p	N	12157
	Continuous force, cooled, at $I_{cw\ eff}$	F_{cw}	N	5667
	Continuous force, not cooled, at $I_{c\ eff}$	F_c	N	1838
	Stall force, cooled, at $I_{sw\ eff}$	F_{sw}	N	3759
	Cogging force at I = 0	F_{cog}	N	24,31
Velocities	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V	v_{Ip600}	m/s	0,88
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V	v_{Iw600}	m/s	2,04
	Limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V	v_{Ip300}	m/s	0,27
	Limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V	v_{Iw300}	m/s	0,88
Currents	Effective ultimate current	$I_{u\ eff}$	A	90,8
	Effective peak current	$I_{p\ eff}$	A	72,7
	Effective continuous current, cooled	$I_{cw\ eff}$	A	24,9
	Effective continuous current, not cooled	$I_{c\ eff}$	A	7,91
	Effective stall current, cooled	$I_{sw\ eff}$	A	16,4
Power losses	Power loss at F_p	P_{Ip}	W	17414
	Power loss at F_{cw}	P_{Iw}	W	2738
	Power loss at F_c	P_{Ic}	W	277
Electrical characteristic values	DC link voltage	U_{DCL}	V	800
	Electrical resistance, phase to phase	R_{20}	Ω	2,20
	Inductance, phase to phase	L	mH	42,88
	Back EMF constant, phase to phase	$k_{û}$	V/(m/s)	190,0
General characteristic values	Pole pair width	$2\tau_p$	–	46
	Motor constant at +20 °C	k_m	N/√W	128,2
	Force constant	k_f	N/A	232,3
	Motor temperature switch-off threshold	ϑ_{PTC}	°C	110
	Attraction force	F_a	N	18615
Cooling conditions	Volume flow	dV/dt	l/min	11,0
	Nominal supply temperature of the cooling water	ϑ_{nf}	°C	20
	Cooling water temperature difference	$\Delta\vartheta$	K	3,6
	Pressure drop	Δp	bar	0,8

500-300	650-300
Z2.8H	**Z3.8H**
19944	26593
18235	24313
8415	11229
2629	3437
5580	7444
36,47	48,63
0,56	0,76
1,42	1,82
0,03	0,20
0,58	0,78
98,4	163,2
78,7	130,5
26,7	44,3
8,17	13,29
17,6	29,2
26275	34725
4047	5357
379	482
800	800
2,82	1,36
54,78	26,57
263,1	211,6
46	46
156,5	181,5
321,6	258,7
110	110
27922	37230
12,0	13,0
20	20
4,8	5,9
1,3	1,9

13 Volume flow and pressure drop

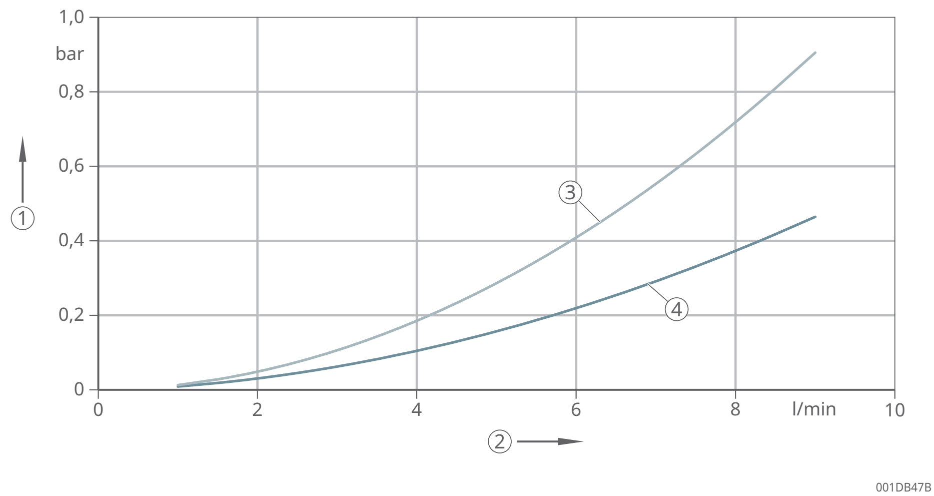
L7-3P-...-100

47 Pressure drop, primary part



1	Pressure drop	2	Volume flow
3	L7-3P-650-100-PRIM	4	L7-3P-500-100-PRIM
5	L7-3P-350-100-PRIM		

48 Pressure drop, end piece and cooling profile

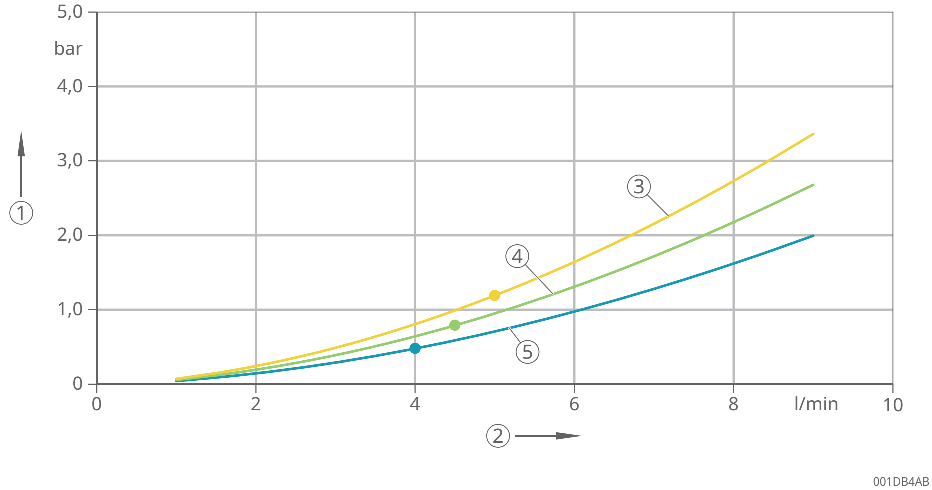


1	Pressure drop	2	Volume flow
3	End piece	4	Cooling profile

13

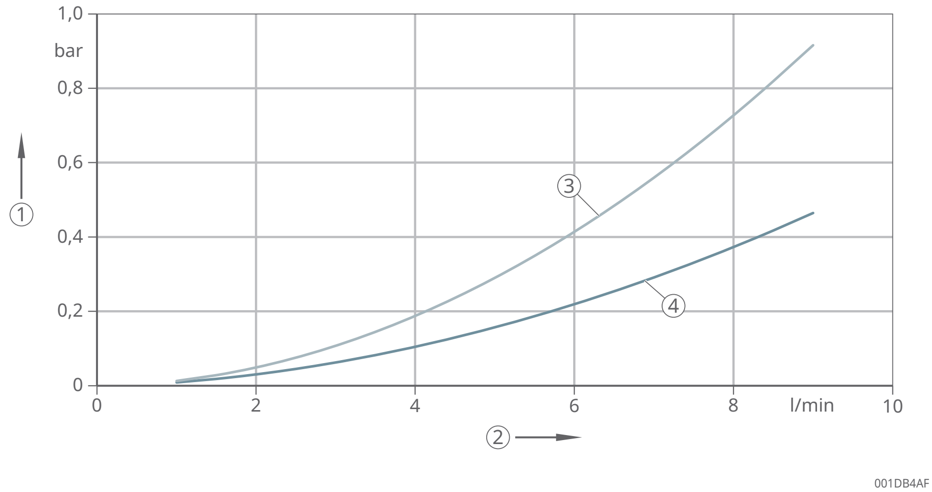
L7-3P-...-150

49 Pressure drop, primary part



1	Pressure drop	2	Volume flow
3	L7-3P-650-150-PRIM	4	L7-3P-500-150-PRIM
5	L7-3P-350-150-PRIM		

50 Pressure drop, end piece and cooling profile

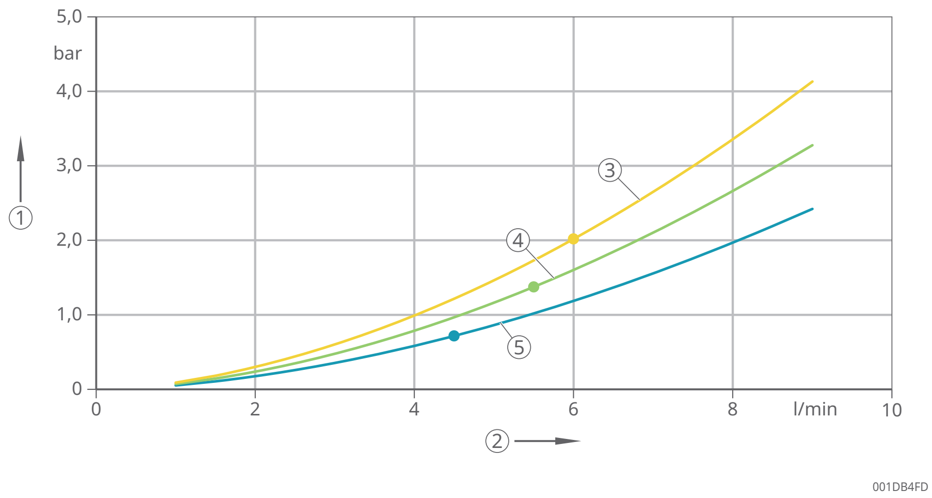


1	Pressure drop	2	Volume flow
3	End piece	4	Cooling profile

13

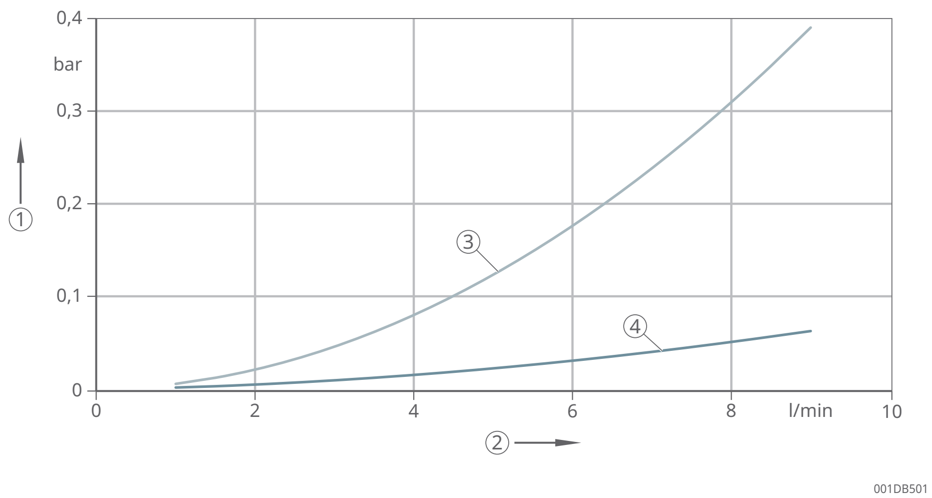
L7-3P-...-200

51 Pressure drop, primary part



1	Pressure drop	2	Volume flow
3	L7-3P-650-200-PRIM	4	L7-3P-500-200-PRIM
5	L7-3P-350-200-PRIM		

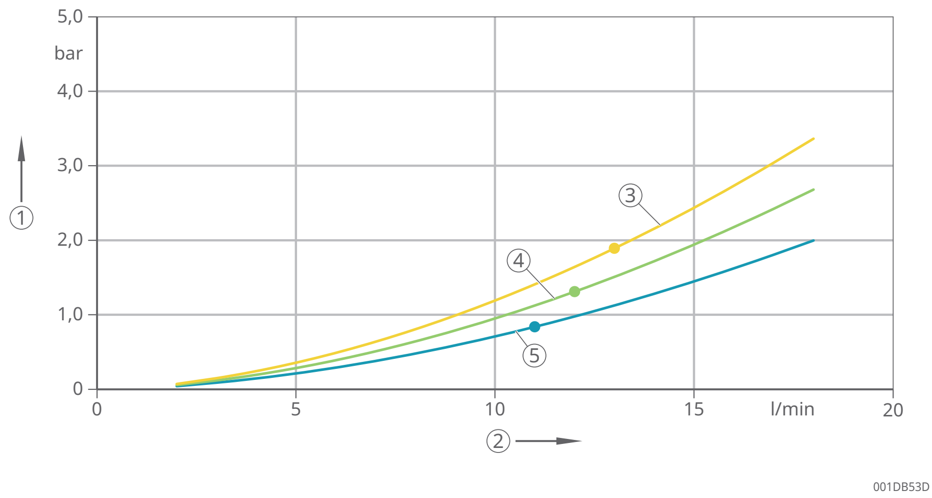
52 Pressure drop, end piece and cooling profile



1	Pressure drop	2	Volume flow
3	End piece	4	Cooling profile

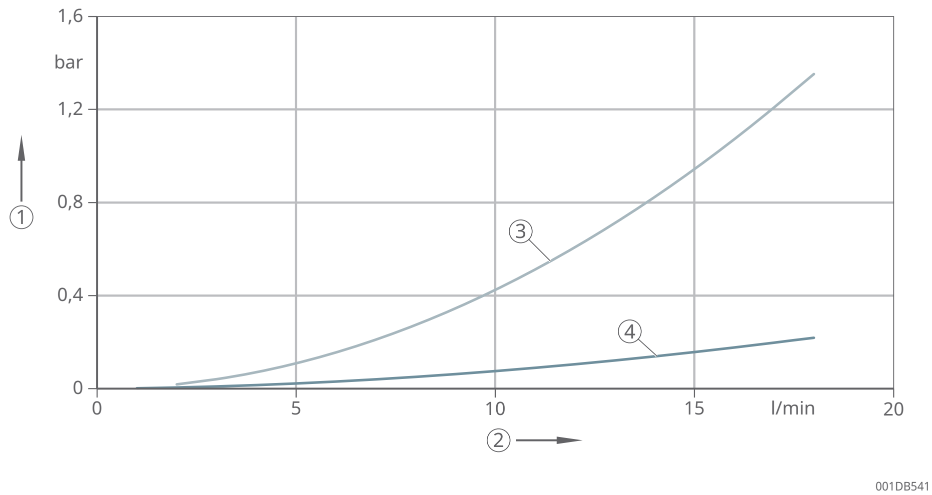
L7-3P-...-300

53 Pressure drop, primary part



1	Pressure drop	2	Volume flow
3	L7-3P-650-300-PRIM	4	L7-3P-500-300-PRIM
5	L7-3P-350-300-PRIM		

54 Pressure drop, end piece and cooling profile



1	Pressure drop	2	Volume flow
3	End piece	4	Cooling profile

14 Glossary

$2\tau_p$, pole pair width

Distance corresponding to a pole pair. τ_p represents the pole width. The pole width has a magnetic field that alternates between N (north) and S (south). The pole width is also referred to as the magnet width.

dV/dt, volume flow

Flow rate per unit of time required for the specified cooling water temperature difference $\Delta\vartheta$ for the given power loss P_{lc} to be achieved.

F_a, attraction force

Magnetic attraction force between the primary part and the secondary part, which varies depending on the distance between the two parts. The value applies to the specified air gap.

F_c, continuous force, not cooled

Motor force at $I_{c\ eff}$ at which the motor can be operated in a thermally stable manner without cooling, but is subject to a temperature increase in the process.

F_{cog}, cogging force

Peak value of the pulsating motor force that occurs in a de-energised state during movement. The amplitude of the cogging force depends on the position of the primary part.

F_{cw}, continuous force, cooled

Motor force at $I_{cw\ eff}$ that is available as a continuous force during rated operation with water cooling. At this force, a temperature difference of 90 K is established between the winding and the cooling system.

f_P (n), pole change frequency

The pole change frequency is calculated from the quotient of the speed in mm/s and the pole pair width. The pole change frequency has units of Hz.

F_p, peak force

Force at $I_{p\ eff}$ that can be reliably achieved in the saturation range and at all operating temperatures. The peak force can be applied for a maximum of 1 ... 3 s. At magnet temperatures up to +60 °C and in pulse mode, F_p can be increased up to the value of F_u.

F_{sw}, stall force, cooled

Motor force that can be continuously applied at standstill and at pole change frequencies of up to approx. 0,1 Hz.

F_u, ultimate force

Max. permissible force at high saturation of the magnetic circuit. The ultimate force may only be applied for <1 s. When approaching the ultimate force, the maximum temperature of the primary part and magnets of +60 °C must be observed. At higher temperatures, the primary part may be destroyed within a very short time and the secondary part may become demagnetised. The ultimate force should not be used as a sizing quantity, but must be taken into account during short-circuit braking.

$I_{c\ eff}$, effective continuous current, not cooled

Current at which the associated power loss leads to a relatively low amount of heating of the motor without forced cooling based on the size of the mounting base.

$I_{cw\ eff}$, effective continuous current, cooled

Current that is permissible during continuous operation with water cooling, from a pole change frequency of 0,1 Hz up to the velocity v_{lw} at the corresponding DC link voltage.

$I_{p\ eff}$, effective peak current

Current that is in the range of iron saturation. We recommend using this current as a sizing quantity; please also see F_p. $I_{p\ eff}$ may be increased up to the limit value $I_{u\ eff}$ if the magnet temperature does not exceed +60 °C and operation is in pulse mode with a pulse duration of 1 s up to a maximum of 3 s.

$I_{sw\ eff}$, effective stall current, cooled

Max. permissible current during continuous operation with water cooling at pole change frequencies of 0 Hz to 0,1 Hz. Because the current is distributed differently in the motor phases, the motor current must be reduced to this value for local overheating to be prevented. In the determination of the effective stall current, the thermally most unfavourable secondary part position is considered.

$I_{u\ eff}$, effective ultimate current

Current at which the magnetic circuit is in high saturation. The max. current density in the winding or the incipient risk of demagnetisation at a magnet temperature of +60 °C determines the effective ultimate current. An I^2t control system can prevent overheating of the primary part, but not demagnetisation of the secondary part.

k_f, force constant

Value which, when multiplied by the current in the linear control range, gives the resulting motor force: $F = I \cdot k_f$.

k_m, motor constant

Value describing the efficiency of the motor. The motor constant represents the ratio of force to power loss.

It remains constant only when the motor is in static operation and within the linear control range. Positioning operations at low velocities and forces are an example of this.

The value varies as a function of temperature. At a winding temperature of +130 °C, the motor constant decreases to 0,84 of its normal value.

$k_{\hat{u}}$, back EMF constant

Voltage constant for generator operation. The peak value of the back EMF generated at the motor terminals is calculated by multiplying the back EMF constant by the velocity: $U_{EMF} = k_{\hat{u}} \cdot v$.

L, inductance, phase to phase

Inductance between 2 motor phases, valid for the linear range between force and current.

P_l, power loss

Thermal power generated in the motor winding, leading to a time-dependent increase in temperature. The temperature rise is influenced by the heat input from the current flowing under the respective operating conditions and by heat dissipation through the cooling system.

Current in the upper control range, at F_p, generates a significant power loss P_l, as power loss increases with the square of the current. The continuous current causes only a relatively small increase in motor winding temperature.

For a motion segment with the required force F, P_l can be calculated in simplified form using the motor constant k_m: $P_l = (F/k_m)^2$.

P_{lc}, power loss

Ohmic power loss at $I_{c\ eff}$.

P_{lp}, power loss

Ohmic peak power loss at $I_{p\ eff}$.

P_{lw}, power loss

Ohmic power loss at $I_{cw\ eff}$.

R_{20}, electrical resistance

Winding resistance between two motor phases at +20 °C. At +130 °C, the winding resistance increases to 1,4 times the normal value.

U_{DCL}, DC link voltage

DC voltage supplied by the converter to the inverter. The inverter then provides the DC link voltage to the motor, minus the losses within the inverter. The DC link voltage determines the achievable velocities.

v_{lp300}, limiting velocity at $I_{p\ eff}$ and U_{DCL} = 300 V

Maximum motor velocity, dependent on the winding, without consideration of dynamic thermal losses and without field weakening, at $I_{p\ eff}$ and U_{DCL} = 300 V. If the velocity is increased without considering field weakening, the available force decreases significantly.

v_{lw300}, limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 300 V

Maximum motor velocity, dependent on the winding, without consideration of dynamic thermal losses and without field weakening, at $I_{cw\ eff}$ and U_{DCL} = 300 V. If the velocity is increased without considering field weakening, the available force decreases significantly.

v_{lp600}, limiting velocity at $I_{p\ eff}$ and U_{DCL} = 600 V

Maximum motor velocity, dependent on the winding, without consideration of dynamic thermal losses and without field weakening, at $I_{p\ eff}$ and U_{DCL} = 600 V. If the velocity is increased without considering field weakening, the available force decreases significantly.

v_{lw600}, limiting velocity at $I_{cw\ eff}$ and U_{DCL} = 600 V

Maximum motor velocity, dependent on the winding, without consideration of dynamic thermal losses and without field weakening, at $I_{cw\ eff}$ and U_{DCL} = 600 V. If the velocity is increased without considering field weakening, the available force decreases significantly.

Δp, pressure drop of the cooling medium

Pressure drop between the inlet and outlet of the cooling medium.

$\Delta\vartheta$, cooling water temperature difference

Max. temperature difference between cooling water inlet and outlet.

ϑ_{nf}, nominal feed temperature

Cooling water inlet temperature required to use $I_{cw\ eff}$ or $I_{sw\ eff}$ continuously while maintaining the remaining cooling conditions ($\Delta\vartheta$ and dV/dt). If these cooling conditions are maintained, with continuous use of $I_{cw\ eff}$ and $I_{sw\ eff}$, the sensor temperature settles to just below ϑ_{PTC} at the least favourable phase angle between the coils.

ϑ_{PTC}, motor temperature switch-off threshold

Temperature at which the servo drive must be shut down to protect the motor from overheating. This temperature is measured using a PTC sensor, which triggers a thermistor motor protection relay connected to the servo drive.

With water cooling, compliance with the specified cooling conditions (dV/dt and $\Delta\vartheta$), and continuous operation at $I_{cw\ eff}$, the motor heats up to just below the switch-off temperature.

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