LEINE LINDE

AN INPUT TO ACHIEVE

FUNCTIONAL SAFETY

Safety first

Leine & Linde – an important part in designing safe operations and safe machines.

The best encoder solutions improve uptime, safety and performance. Leine & Linde encoders are known for their accuracy, enduring both harsh working conditions and long working hours.

Achieve functional safety in environments where temperature differences, dirt, shock, and vibrations are common. Meet some of the most robust rotary encoders on the market.

The functional safety concept

To protect workers and to be able to sell a machine within the European market it is mandatory that the machine complies with the machinery directive, 2006/42/EC, and by that fulfills the part concerning functional safety. Functional safety is about reducing hazardous risks to maintain a safe machine for the operator.

Performance level and safety integrity level

To show conformance to the machinery directive the machine manufacturer has to comply to a standard from the list of harmonized standards (www.newapproach.org). Unlike the machinery directive, fulfillment of the standards is not legally mandated. However, if the harmonized standards are fulfilled, it is considered that all safety requirements of the machinery directive are as well.

The harmonized standards for showing compliance to the machinery directive, regarding functional safety, are either EN ISO 13849 or EN IEC 62061. EN ISO 13849 derives from EN 954-1 and is used for safety solutions where the safety is classified according to performance level PL a, b, c, d or e in ascending safety-related effectiveness. For functional safety of safety-related electrical, electronic and programmable electronic control systems, EN IEC 62061 is the choice. Note, in EN IEC 62061 the functional safety system is composed of subsystems certified according to IEC 61508 which classifies the various safety categories in safety integrity levels (SIL 1, 2, 3 and 4). IEC 61508 also shows a probabilistic view of dangerous failures. Each of the various SIL levels describes a maximum permissible residual risk for a dangerous failure (PFH) of a machine or machine system.

The standards above are correlating to each other in some aspects; if low-complexity subsystems are designed according to EN IEC 62061 the standard refers to EN ISO 13849. It is similar for the performance level e within EN ISO 13849 which is referring to IEC 61508-3 because it covers safety-related embedded software for components with PL_r = e.

Risk assessment and risk reduction

When designing a machine, it is mandatory for the machine builder to estimate how dangerous the machine will be, if a loss of the safety function occurs. This is done according to EN ISO 12100, by analyzing the risks and evaluating how to eliminate or minimize them. By performing the risk analysis a required risk reduction level is established (according to either PL or SIL) and this is the level of safety that the functional safety system has to fulfill in order to be considered as a human safe machine.

Furthermore the system has to be calculated based on the values of its containing components in order to meet the risk reduction level. It is within this calculation the reliability value of the encoder is needed.

SIL2 or PLd

The Leine & Linde encoders are to be used as input components in a functional safety system. Therefore $MTTF_d$ (EN ISO 13849) or PFH_d (IEC 61508) values are provided, for calculation of the safety in the system and thereby to make sure it meets the requirements of the risk reduction level. For most industrial applications where the encoders are used, SIL2/PLd is enough to meet the safety requirements. However it is possible to achieve different levels of risk reduction depending on the encoder input and the system architecture, from a minimum level of SIL1/PLc to a maximum level SIL3/PLe.

Abbreviations

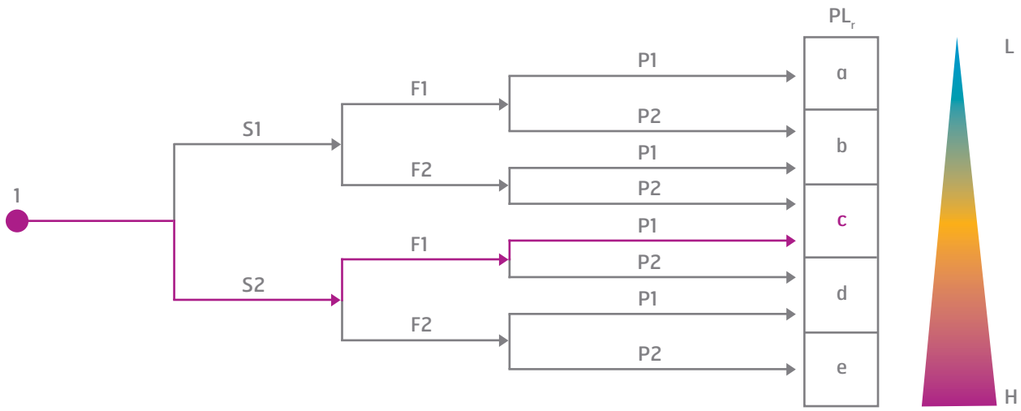
$MTTF_d$ = Mean time to dangerous failure [years]
PFH = Probability of a dangerous failure per hour [h^{-1}]
SIL = Safety integrity level
PL = Performance level

Evaluation of performance level

The evaluation is required to make sure that the designed system has a performance level that is equivalent or higher than the required performance level c (PL_r=c) on this page. This to be sure that the machine will be safe for the operator.

Risk graph for determining required PL_r according to EN ISO 13849-1

This graph contains the three factors that are used within the risk assessment to determine how high the risk of injury can get if loss of the safety function.



Key

1 Starting point for evaluation of safety function's contribution to risk reduction.

L Low contribution to risk reduction

H High contribution to risk reduction

PL_r Required performance level

Risk parameters

S Severity of injury

S1 Slight (normally reversible injury)

S2 Serious (normally irreversible injury or death)

F Frequency and/or exposure to hazard

F1 Seldom-to-less-often and/or exposure time is short

F2 Frequncy-to-continuous and/or exposure time is long

P Possibility of avoiding hazard or limiting harm

P1 Possible under specific conditions

P2 Scarcely possible

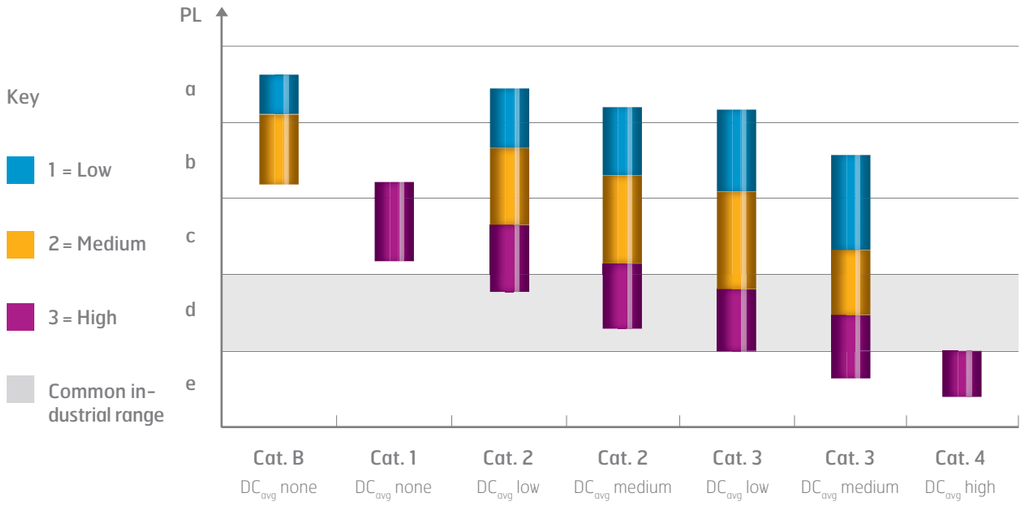
Tables from EN ISO 13849-1 to establish the performance level

The relationship between $MTTF_d$, Diagnostic coverage (DC) and the category of the system results in the performance level of it.

Denotation of each channel	$MTTF_d$
Low	3 years ≤ $MTTF_d$ < 10 years
Medium	10 years ≤ $MTTF_d$ < 30 years
High	30 years ≤ $MTTF_d$ < 100 years

Key
PL performance level
1 $MTTF_d$ of each channel = low
2 $MTTF_d$ of each channel = medium
3 $MTTF_d$ of each channel = high

Denotation	Range
None	DC < 60%
Low	60% ≤ DC < 90%
Medium	90% ≤ DC < 99%
High	99% ≤ DC



After finding out the required performance level for the application, use the examples on pages 8-9 to understand how the encoders meet the level in question. Depending on the design of the functional safety system, it is possible to achieve different performance levels.

System solutions

Leine & Linde encoders are suitable for functional safety systems in all heavy duty applications. Depending on the system components as well as the system category, DC and MTTFd, different levels of risk reduction can be achieved.

PLc achieved with system category 1 according to EN ISO 13849-1

For some applications it is enough using a single channel system due to either other combinations of safety equipments or due to the low hazardous risks. This safety system cuts the current supply to the motor to make sure a stop.

1. **Encoder** 1 Vpp, $MTTF_d$ > 100 years, DC* = 99%
2. **Logic** $MTTF_d$ > 100 years, DC = 90%
3. **Output** $MTTF_d$ > 100 years, DC = 90%

* The diagnostic coverage (DC) is based on the monitoring of the logic.

$$\frac{1}{\frac{1}{MTTF_{d\ encoder}} + \frac{1}{MTTF_{d\ logic}} + \frac{1}{MTTF_{d\ output}}} = MTTF_{d\ system}\ [years]$$

This results in a $MTTF_d$ value > 100 years.

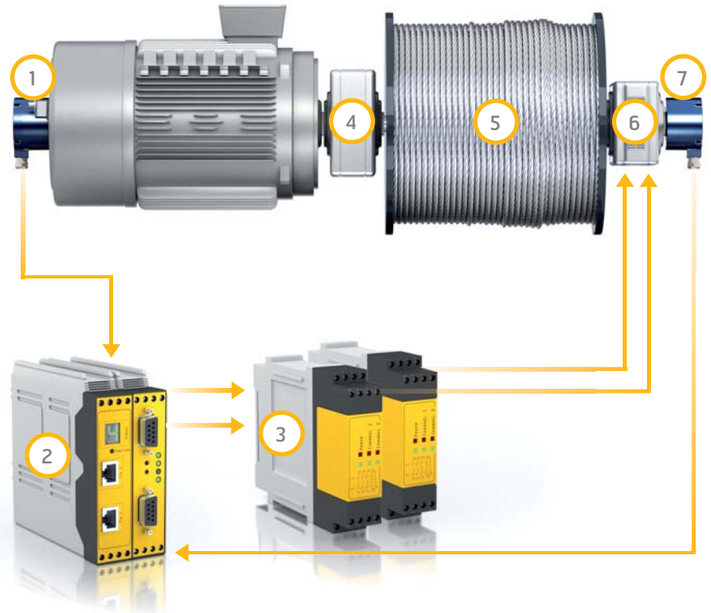
$$\frac{\frac{DC_{encoder}}{MTTF_{d\ encoder}} + \frac{DC_{logic}}{MTTF_{d\ logic}} + \frac{DC_{output}}{MTTF_{d\ output}}}{\frac{1}{MTTF_{d\ encoder}} + \frac{1}{MTTF_{d\ logic}} + \frac{1}{MTTF_{d\ output}}} = DC_{avg\ system}\ [\%]$$

This calculation results in a DC_{avg} = 90,5%.

With these values the performance level of the system is established as PLc according to the table on page 7.

PLd achieved with system category 3 according to EN ISO 13849-1

In this example the use of two encoders creates a two channel system for redundancy to ensure functioning of the safety function: to stop the drum if a hazardous situation occurs.



1. **Encoder** 1 Vpp, $MTTF_d$ > 100 years, DC* = 99%
2. **Logic** $MTTF_d$ > 100 years, DC = 90%
3. **Outputs** $MTTF_d$ > 100 years, DC = 90%
4. **Gearbox** (Failures of the gearbox has to be considered when designing the system)
5. **Drum**
6. **Brake** $B10_d = 6 \times 10^6$ (Redundant accordning to category 3)
7. **Encoder** 1 Vpp, $MTTF_d$ > 100 years, DC* = 99%

* The diagnostic coverage (DC) is based on the monitoring of the logic.

$$\frac{1}{\frac{1}{MTTF_{d\ encoder\ 1}} + \frac{1}{MTTF_{d\ logic}} + \frac{1}{MTTF_{d\ output}} + \frac{1}{MTTF_{d\ brake}}} = MTTF_{d\ channel\ 1}$$

$$\frac{1}{\frac{1}{MTTF_{d\ encoder\ 2}} + \frac{1}{MTTF_{d\ logic}} + \frac{1}{MTTF_{d\ output}} + \frac{1}{MTTF_{d\ brake}}} = MTTF_{d\ channel\ 2}$$

$$\frac{2}{3}\left(MTTF_{d\ ch\ 1} + MTTF_{d\ ch\ 2} - \frac{1}{\frac{1}{MTTF_{d\ ch\ 1}} + \frac{1}{MTTF_{d\ ch\ 2}}}\right) = MTTF_{d\ system}\ [years]$$

This results in a $MTTF_d$ value > 100 years.

$$\frac{\frac{DC_{encoder\ 1}}{MTTF_{d\ encoder\ 1}} + \frac{DC_{encoder\ 2}}{MTTF_{d\ encoder\ 2}} + \frac{DC_{logic}}{MTTF_{d\ logic}} + \left(2x\frac{DC_{output}}{MTTF_{d\ output}}\right) + \left(2x\frac{DC_{brake}}{MTTF_{d\ brake}}\right)}{\frac{1}{MTTF_{d\ encoder\ 1}} + \frac{1}{MTTF_{d\ encoder\ 2}} + \frac{1}{MTTF_{d\ logic}} + \left(2x\frac{1}{MTTF_{d\ output}}\right) + \left(2x\frac{1}{MTTF_{d\ brake}}\right)} = DC_{avg\ system}\ [\%]$$

This calculation results in a DC_{avg} = 98,2%.

Please note that this are only brief examples and therefore not to be used as guidance. For more detailed information regarding the calculation, please refer to EN ISO 13849-1.

With these values the performance level of the system is established as PLd according to the table on page 7.

Mechanical safety

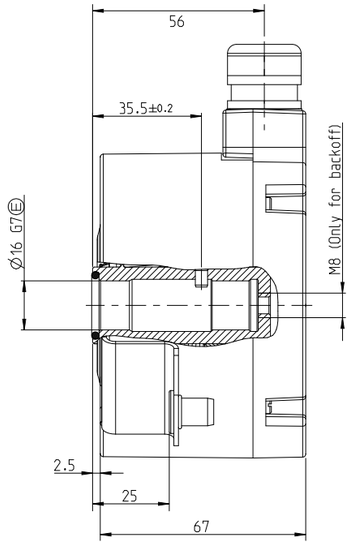
In addition to tightening screws slip-free mechanical adaption of shaft inlet is required to ensure a safe installation.

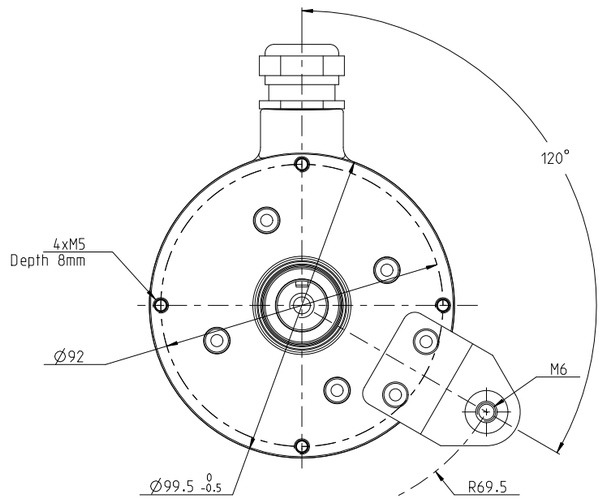
If a hollow shaft encoder is mounted to a solid round shaft, the risk of slipping is high and undetectable. To avoid this scenario Leine & Linde provides slip-free shaft solutions, such as the key in the 800 series hollow shaft encoder, which prevents the user to mount the encoder to a solid round adapter shaft.

For the 500 and the 600 encoder series solid shaft with flat or key is available.

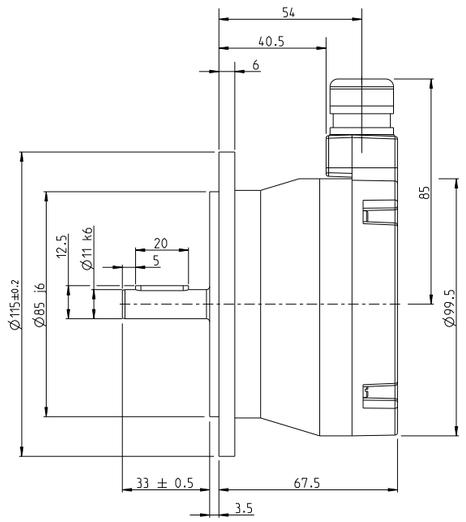
For more information regarding solutions for mechanical safety, please contact Leine & Linde.

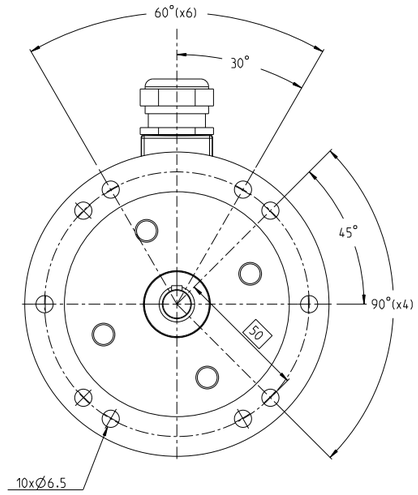
Hollow shaft encoder with key





Solid shaft encoder with key





Encoders for a safe system

This spread offers an overview of rotary encoders available with reliability values for functionally safe systems. There is also a solution where functional safety is integrated into the product: the Leine & Linde FSI series. Thanks to the serie's SIL2/PLd certified safe functions, the machine directives are fulfilled just by using this solution correctly.

The 800 series heavy duty encoder

Available with 1 Vpp for use in more demanding safety system where the required risk reduction is high.

Output signal	1 Vpp, TTL, HTL or HCHTL
Encapsulation	IP67 (IP66 at shaft inlet)
Rotation speed max	6000 rpm
Force (radial / axial)	300 N / 100 N
Vibration	≤ 200 m/s²
Shock	≤ 1500 m/s²
$MTTF_d$ value	1 Vpp, 5 V: 770 years, terminal connection HCHTL, 9-30 V: 421 years, terminal connection
PFH value	1 Vpp, 5 V: 4,173E-7 h⁻¹, terminal connection HCHTL, 9-30 V: 7,425E-7 h⁻¹, terminal connection

The 700 series compact encoder

In tight spaces where there is need for a robust encoder, the 700 series is the option.

Output signal	1 Vpp, HTL or HCHTL
Encapsulation	IP67 (IP66 at shaft inlet)
Rotation speed max	6000 rpm
Force (radial / axial)	50 N / 100 N
Vibration	≤ 200 m/s²
Shock	≤ 1500 m/s²
$MTTF_d$ value	1 Vpp, 5 V: 483 years, connector or cable HCHTL, 9-30 V: 224 years, connector or cable
PFH value	1 Vpp, 2,36E-7 h⁻¹, connector or cable HCHTL, 5,8E-7 h⁻¹, connector or cable

The 600 series industrial encoder

The inductive 600 series absolute encoder with SSI interface has a 1 Vpp output signal for use within functional safety applications.

Output signal	SSI, 1 Vpp, 32 ppr
Encapsulation	IP67
Rotation speed max	12000 rpm
Force (radial / axial)	125 N / 100 N
Vibration	≤ 300 m/s²
Shock	≤ 2000 m/s²
$MTTF_d$ value	1 Vpp, 9-30 V: 715 years, M23 connector
PFH value	9-30 V: 3,555E-7 h⁻¹, M23 connector

The 500 series robust encoder

When looking for a Ø58 mm encoder with unrivalled performance. With its HTL output the encoder can be used in environment where the cable distances are long and electronic signals are required.

Output signal	HTL
Encapsulation	IP67 (IP66 at shaft inlet)
Rotation speed max	6000 rpm
Force (radial / axial)	60 N / 50 N
Vibration	≤ 300 m/s²
Shock	≤ 2000 m/s²
$MTTF_d$ value	HTL, 6 channel, 9-30 V: 773 years
PFH value	HTL, 6 channel, 9-30 V: 5,853E-7 h⁻¹

The FSI series – functional safety integrated

The FSI series is a functional safety product series provided by Leine & Linde. The series offers a great variety of functionalities, with absolute and incremental encoder signals, shaft and hollow-shaft mounting, as well as robust construction and encapsulation.

The encoder solutions are SIL2/PLd certified, including different safety functions such as overspeed, acceleration, end limits, and standstill. The FSI series monitors its own performance in a functionally safe manner, and thereby it can serve a functionally safe system with or without a functionally safe certified PLC.

Read more in the product brochure for the FSI series.

FUNCTIONAL SAFETY SIL2/PLd CERTIFIED

For more information about the encoder series please visit www.leinelinde.com.

Electronics

Square waves

Square waves are the most common signal type for an incremental encoder. Leine & Linde's products are supplied as standard with 6 channels. Signal S00 is followed by signal S90, which is displaced 90 electrical degrees. The two inverted signals S00\ and S90\ enable differential transmission, which reduces the sensitivity of the signals to electrical interference. To check the position of the shaft, a reference pulse is produced once per revolution, Sref with its inverse Sref\.

There are several variations of electrical interface with different supply voltages and signal levels. When choosing an interface, it is necessary to take into account factors in the motor's operating environment. The exact properties of the interface is affected by frequency, cable length and temperature.

Interface	TTL	HTL	HCHTL
Supply	5 Vdc	9-30 Vdc	9-30 Vdc
Output signal	5 Vdc	9-30 Vdc	9-30 Vdc
Suitable for	Low frequencies over short cables	High frequencies over medium-length cables	Medium frequencies over long cables
Max cable length	50 m at 50 kHz	100 m at 100 kHz	350 m at 100 kHz
Temperature	-40 .. +100 °C	-40 .. +100 °C	-40 .. +85 °C

Sine waves

Sine waves are an alternative form of output signal. The analogue signal produces a unique amplitude for each position on the wave, allowing interpolation and very high resolutions. The interface 1 Vpp is often used in safety-critical applications where detection are required of extremely small movements.

For further information regarding our encoders and functional safety, please contact your nearest distributor or call Leine & Linde at +46-(0)152-265 00. The wide range of encoder variation is always available at www.leinelinde.com.

Contact us

SWEDEN / HEAD OFFICE
T +46-(0)152-265 00
F +46-(0)152-265 05
info@leinelinde.com

BRAZIL
T +55-19-3291 8425
F +55-19-3367 5658
info@leinelinde.com.br

CHINA
T +86-(021)-525 835 66
F +86-(021)-525 835 99
info@leinelinde.cn

DENMARK
T +45-862-308 34
info@leinelinde.dk

FINLAND
T +358-(0)9-561 72 00
F +358-(0)9-561 72 020
info@leinelinde.fi

GERMANY
T +49-(0)40-3176758-60
F +49-(0)40-3176758-65
info@leinelinde.de

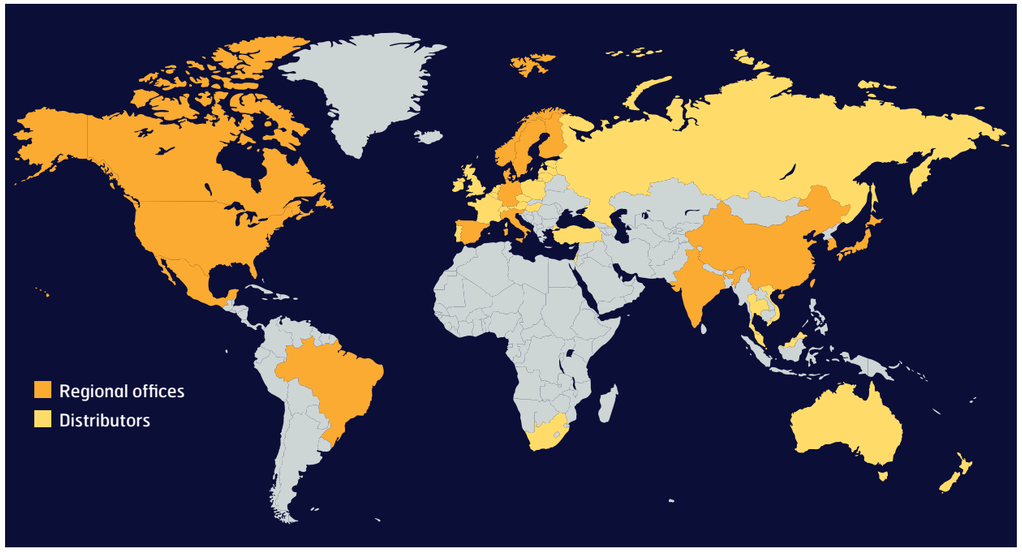
INDIA
T +91-11-261 725 04
F +91-11-261 654 49
info@leinelinde.in

ITALY
T +39-039-596 01 08
F +39-039-971 22 08
info@leinelinde-ltn.it

SOUTH KOREA
T +82-(0)51-746 54 20
F +82-(0)51-746 54 21
info@leinelinde.co.kr

SPAIN
T +34-93-574 23 02
F +34-93-560 57 60
info@leinelinde.es

Leine & Linde's worldwide presence. Read more at www.leinelinde.com



The best encoders are those you never have to think about. Those that simply do their job – year after year. Leine & Linde develops and manufactures customised encoder solutions for demanding environments, advanced measuring systems for accurate feedback of speed and position.

LEINE LINDE

+46-(0)152-265 00 www.leinelinde.com

Part no. 1067032-01, ver. 04