HEIDENHAIN

Linear Encoders

For Numerically Controlled
Machine Tools

01/2022

Contents

Further information is available on the Internet at *www.heidenhain.com* as well as upon request.

Brochures regarding:
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- HEIDENHAIN subsequent electronics
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- Measuring devices for machine tool inspection and acceptance testing

Technical information regarding:
- Interfaces of HEIDENHAIN encoders
- Accuracy of feed axes
- Safety-related position measuring systems
- EnDat 2.2—bidirectional interface for position encoders
- Encoders for direct drives

This brochure supersedes all previous editions, which thereby become invalid.

The basis for ordering from HEIDENHAIN is always the brochure edition valid when the order is made.

Standards (ISO, EN, etc.) apply only where explicitly stated in the brochure.

Further information:

For comprehensive descriptions of all available interfaces, as well as general electrical information, please refer to the *Interfaces of HEIDENHAIN Encoders* brochure.

Linear encoders for numerically controlled machine tools

Linear encoders from HEIDENHAIN for numerically controlled machine tools can be used nearly everywhere. They are ideal for machines and other equipment whose feed axes are in a closed loop, such as milling machines, machining centers, boring mills, lathes, and grinding machines. The beneficial dynamic behavior of linear encoders, their high permissible traversing speed, and their acceleration in the direction of measurement predestine them for use on highly-dynamic conventional axes as well as on direct drives.

HEIDENHAIN also supplies linear encoders for other applications, such as:
- Manual machine tools
- Presses and bending machines
- Automation and production equipment

Advantages of linear encoders
If a linear encoder is used for measurement of the slide position, the position control loop includes the complete feed mechanics. This is referred to as Closed Loop operation. Transfer errors from the mechanics can be detected by the linear encoder on the feed axis, and corrected by the control electronics. This makes it possible to eliminate a number of potential error sources:
- Positioning error due to heat generation in the recirculating ball screw
- Reversal error
- Kinematic error through the ball-screw pitch error

Linear encoders are therefore indispensable for machine tools on which high **positioning accuracy** and a high **machining rate** are essential.

Mechanical design
Linear encoders for numerically controlled machine tools are sealed measuring devices: an aluminum housing protects the scale, the scanning carriage, and its guide from chips, dust, and splashing water. Downward-oriented elastic lips seal the housing.

The scanning carriage travels along the scale on a low-friction guide. A coupling connects the scanning carriage with the mounting block and compensates the misalignment between the scale and the machine slide.

Depending on the encoder model, lateral and axial offsets of ±0.2 mm to ±0.3 mm between the scale and mounting block are permissible.

Further information:
Please request further documentation or inform yourself on the Internet at *www.heidenhain.de*.

Thermal characteristics
Increasingly faster machining times with fully encapsulated machines cause ever higher temperatures in the machine's working space. Therefore, the thermal behavior of the linear encoders used becomes increasingly important, since it is an essential criterion for the working accuracy of the machine.

As a general rule, the thermal behavior of the linear encoder should match that of the workpiece or measured object. During temperature changes, the linear encoder must expand or contract in a defined, reproducible manner. Linear encoders from HEIDENHAIN are designed for this.

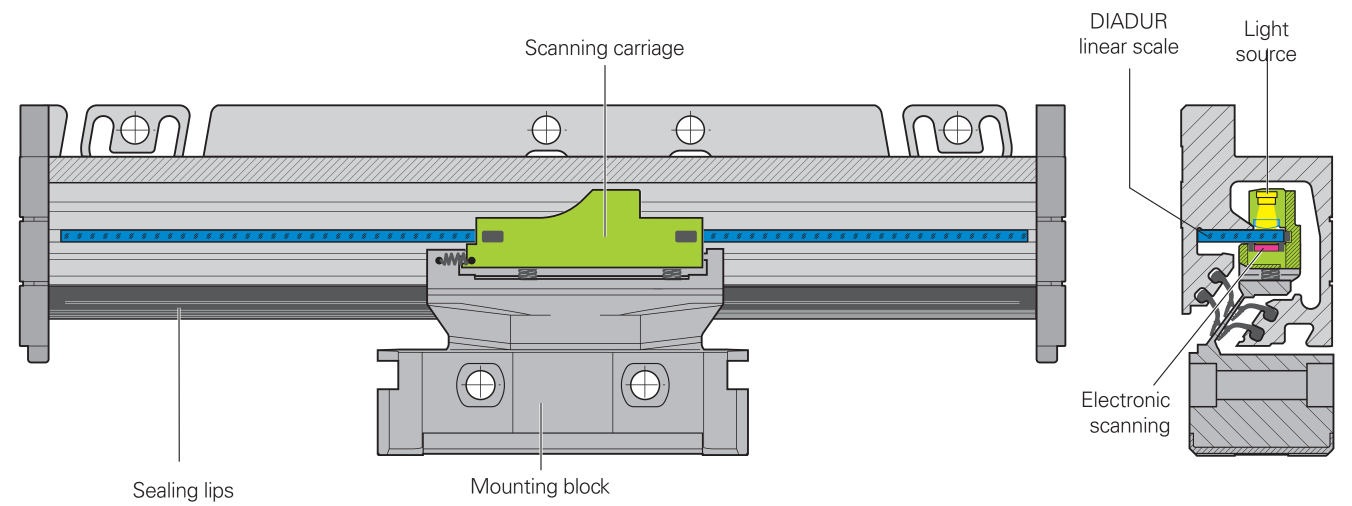
The graduation carriers of HEIDENHAIN linear encoders have defined coefficients of linear thermal expansion (see *Specifications*). This makes it possible to select the linear encoder whose thermal behavior is best suited to the application.

Dynamic behavior
Efficiency and performance improvements in machine tools require ever higher feed rates and accelerations. Of course, they must not compromise machining accuracy. In order to transfer rapid and yet exact feed motions, very high demands are placed on rigid machine design as well as on the linear encoders used.

Linear encoders from HEIDENHAIN are characterized by their high rigidity in the measuring direction. This is a very important prerequisite for high-quality contouring accuracy of a machine tool. In addition, the low mass of moving components contributes to their excellent dynamic behavior.

Availability
The feed axes of machine tools travel quite large distances—a typical value is 10000 km in three years. This is why sturdy encoders with good long-term stability are especially important: they ensure the constant availability of the machine.

Due to the details of their design, linear encoders from HEIDENHAIN function properly even after years of operation.
A long service life is ensured by the contact-free photoelectric scanning of the measuring standard and by the ball-bearing guidance of the scanning carriage in the scale housing. Thanks to their enclosure, special scanning principles, and—if required—a sealing air connection, the linear encoders are particularly tolerant to contamination. The complete shielding design ensures a high degree of electrical noise immunity.



Schematic design of the **LC 115** sealed linear encoder

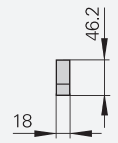
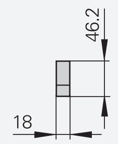
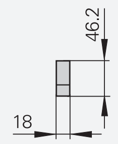
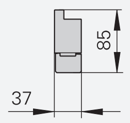
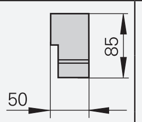
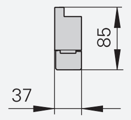
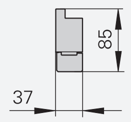
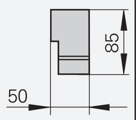
Selection guide

Linear encoders with slimline scale housing

The linear encoders with **slimline scale housing** are designed for **limited installation space**. Larger measuring lengths and higher acceleration loads are possible through the use of a mounting spar or clamping elements.

Linear encoders with full-size scale housing

Linear encoders with **full-size scale housing** are characterized by their **sturdy design, high resistance to vibration,** and **large measuring lengths**. As a connection between the scanning carriage and the mounting block, they have an "oblique web," which permits **vertical and horizontal mounting** with the same degree of protection.

	Cross section	Accuracy grade	Max. interpolation error	Measuring length (ML)	Signal period	Interface	Model	Page
Absolute position measurement • Glass scale		±5 µm ±3 µm	±0.1 µm	70 mm to 1240 mm *With mounting spar or clamping elements:* 70 mm to 2040 mm	–	EnDat 2.2	**LC 415**[2]	**22**
					20 µm	EnDat 2.2 with ∿ 1 VPP	**LC 485**	
					–	DRIVE-CLiQ	**LC 495 S**	**24**
						Fanuc αi	**LC 495 F**	
						Mitsubishi	**LC 495 M**	
						Panasonic	**LC 495 P**	
Incremental linear measurement with very high repeatability • Steel scale • Small signal period		±5 µm ±3 µm	±0.04 µm	50 mm to 1220 mm	4 µm	∿ 1 VPP	**LF 485**	**34**
Incremental linear measurement • Glass scale		±5 µm ±3 µm	±0.2 µm	70 mm to 1240 mm *With mounting spar:* 70 mm to 2040 mm	20 µm	∿ 1 VPP	**LS 487**	**38**
					–	⊓⊔TTL	**LS 477**	
Absolute position measurement • Glass scale		±5 µm ±3 µm	±0.1 µm[1]	140 mm to 4240 mm	–	EnDat 2.2	**LC 115**[2]	**26**
					20 µm	EnDat 2.2 with ∿ 1 VPP	**LC 185**	
					–	DRIVE-CLiQ	**LC 195 S**	**28**
						Fanuc αi	**LC 195 F**	
						Mitsubishi	**LC 195 M**	
						Panasonic	**LC 195 P**	
Absolute position measurement For large measuring lengths • Steel scale tape		±5 µm	±0.4 µm	440 mm to 28040 mm	–	EnDat 2.2	**LC 211**	**30**
					40 µm	EnDat 2.2 with ∿ 1 VPP	**LC 281**	
					–	Fanuc αi	**LC 291 F**	
						Mitsubishi	**LC 291 M**	
Incremental linear measurement with very high repeatability • Steel scale • Small signal period		±3 µm ±2 µm	±0.04 µm	140 mm to 3040 mm	4 µm	∿ 1 VPP	**LF 185**	**36**
Incremental linear measurement • Glass scale		±5 µm ±3 µm	±0.2 µm	140 mm to 3040 mm	20 µm	∿ 1 VPP	**LS 187**	**40**
					–	⊓⊔TTL	**LS 177**	
Incremental linear measurement for large measuring lengths • Steel scale tape		±5 µm	±0.8 µm	440 mm to 30040 mm Up to 72040 mm upon request	40 µm	∿ 1 VPP	**LB 382**	**42**

[1] For measuring lengths > 3040 mm: ±0.4 µm at the butt joint (at approx. 3100 mm)

[2] Connectable to Yaskawa interface via EIB 3391Y

LC 415

LF 485
LS 487

LC 115

LF 185

LC 211

Measuring principles
Measuring standard

HEIDENHAIN encoders with optical scanning incorporate measuring standards of periodic structures known as graduations.

These graduations are applied to a carrier substrate made of glass or steel. For encoders with large measuring lengths, steel tape is used as the scale substrate.

HEIDENHAIN manufactures the precision graduations in the following specially developed, photolithographic processes:

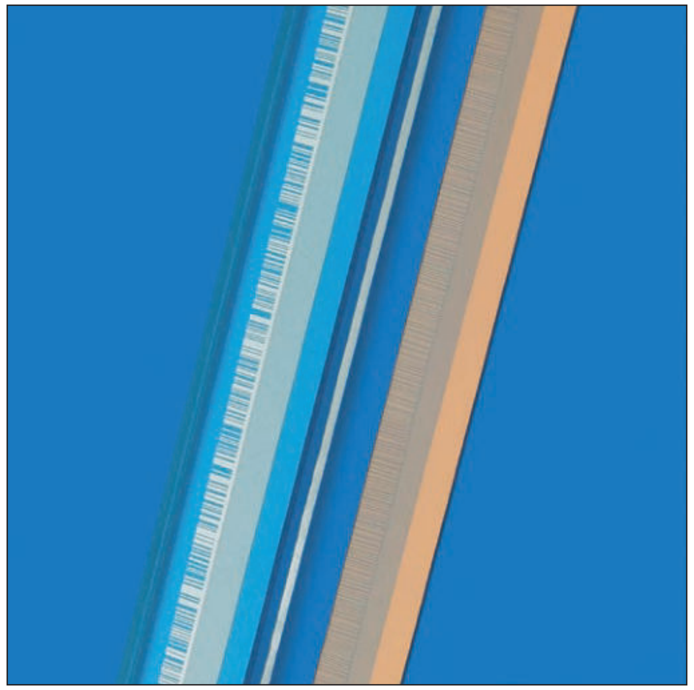
- METALLUR: contamination-tolerant graduation consisting of metal lines on gold; typical grating period: 40 µm
- DIADUR: extremely robust chromium lines on glass (typical grating period: 20 µm) or three-dimensional chromium structures (typical grating period: 8 µm) on glass
- SUPRADUR phase grating: optically three-dimensional, planar structure; particularly tolerant to contamination; typical grating period: 8 µm and finer
- OPTODUR phase grating: optically three-dimensional, planar structure with particularly high reflectance; typical grating period: 2 µm and finer

Along with the very fine grating periods, these processes permit high edge definition and excellent homogeneity of the graduation. Together with the photoelectric scanning method, this high edge definition is critical for the high quality of the output signals.

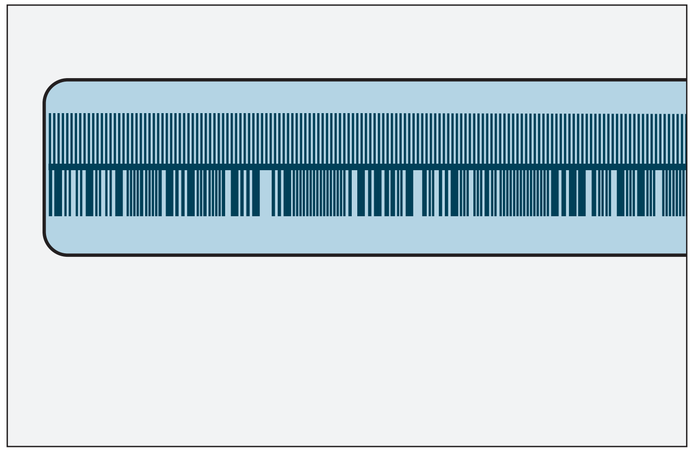
The master graduations are manufactured by HEIDENHAIN on custom-built, high-precision dividing engines.

Absolute measuring method

With the **absolute measuring method**, the position value is immediately available upon switch-on of the encoder and can be requested at any time by the subsequent electronics. There is no need to jog the axes to find the reference position. The absolute position information is read **from the scale graduation**, which is designed as a serial absolute code structure. A separate incremental track is interpolated for the position value and is simultaneously used to generate an optional incremental signal.



Graduations of absolute linear encoders



Schematic representation of an absolute code structure with an additional incremental track (LC 485 as example)

Incremental measuring method

With the **incremental measuring method**, the graduation is arranged as a periodic grating structure. The position information is obtained **through the counting** of individual increments (measuring steps) from any set point of origin. Since the ascertainment of positions requires an absolute reference, the scales or scale tapes feature an additional track bearing a **reference mark**. The absolute position on the scale, established by the reference mark, is gated with exactly one signal period.

The reference mark must therefore be traversed before an absolute reference can be established or before the most recently selected reference point is found.

In the most unfavorable case, machine movements over sizeable sections of the measuring range may be necessary. To speed up and simplify such "reference runs," many HEIDENHAIN encoders feature **distance-coded reference marks**—multiple reference marks that are individually spaced in accordance with a mathematical algorithm. The subsequent electronics find the absolute reference after traversing two successive reference marks—thus after a traverse path of only a few millimeters (see table below).

Encoders with distance-coded reference marks are identified with a "C" following the model designation (e.g., LS 487C). With distance-coded reference marks, the **absolute reference** is calculated by counting the increments between two reference marks and by applying the following formula:

$$P_1 = (\text{abs } R - \text{sgn } R - 1) \cdot \frac{N}{2} + (\text{sgn } R - \text{sgn } D) \cdot \frac{\text{abs } M_{RR}}{2}$$

and

$$R = 2 \cdot M_{RR} - N$$

Where:

P_1 = Position of the first traversed reference mark in signal periods

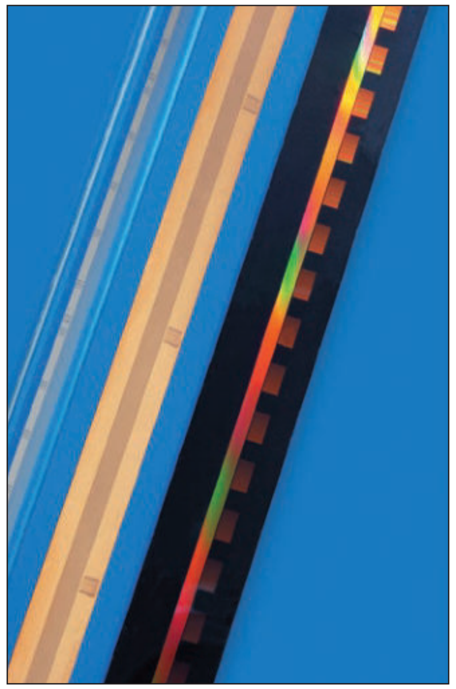
abs = Absolute value

sgn = Algebraic sign function ("+1" or "–1")

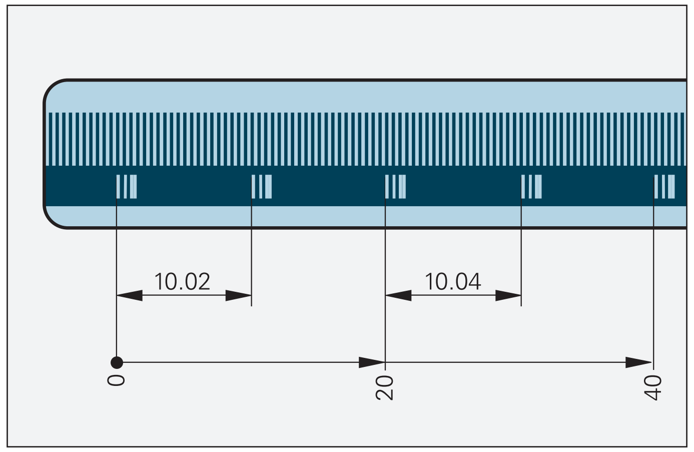
M_{RR} = Number of signal periods between the traversed reference marks

N = Nominal increment between two fixed reference marks in signal periods (see table below)

D = Direction of traverse (+1 or –1). Traverse of scanning unit to the right (when properly installed) equals +1



Graduations of incremental linear encoders



Schematic representation of an incremental graduation with distance-coded reference marks (LS encoder as example)

	Signal period	Nominal increment N in signal periods	Maximum traverse
LF	4 µm	5000	20 mm
LS	20 µm	1000	20 mm
LB	40 µm	2000	80 mm

Photoelectric scanning

Most HEIDENHAIN encoders utilize the photoelectric scanning principle. Photoelectric scanning is performed without contact and thus does not induce wear. This method detects even extremely fine graduation lines with a width of only a few micrometers and generates output signals with very small signal periods.

The finer the grating period of a measuring standard is, the greater the effect of diffraction on photoelectric scanning. HEIDENHAIN linear encoders employ two scanning principles:

- The **imaging scanning principle** for grating periods of 20 µm and 40 µm
- The **interferential scanning principle** for very fine graduations with grating periods of, for example, 8 µm.

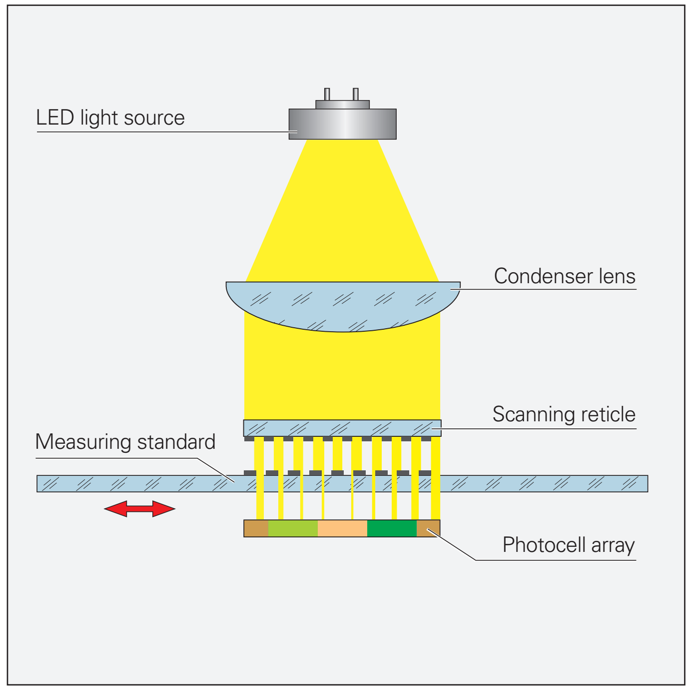
Imaging scanning principle
Put simply, the imaging scanning principle uses projected-light signal generation: two gratings with equal or similar grating periods—the scale and the scanning reticle—are moved relative to each other. The carrier material of the scanning reticle is transparent, whereas the graduation of the measuring standard may be applied to a transparent material or to a reflective material.

When parallel light passes through a grating, light and dark fields are projected at a particular distance. At this location there is an index grating. When the two gratings move relative to each other, the incident light is modulated: If the gaps are aligned, light passes through. If the lines of one grating coincide with the gaps of the other, no light passes through. An array of photovoltaic cells converts these variations in light intensity into electrical signals. The specially structured grating of the scanning reticle filters the light to generate nearly sinusoidal output signals.

The smaller the grating period of the grating structure is, the closer and more tightly toleranced the gap must be between the scanning reticle and the scale.

The LC, LS, and LB linear encoders use the imaging scanning principle.

Imaging scanning principle



Interferential scanning principle
The interferential scanning principle exploits the diffraction and interference of light on finely divided gratings in order to produce the signals used to measure displacement.

A step grating is used as the measuring standard: reflective lines with a height of 0.2 µm are applied to a flat, reflective surface. In front of this is the scanning reticle—a transparent phase grating with the same grating period as the scale.

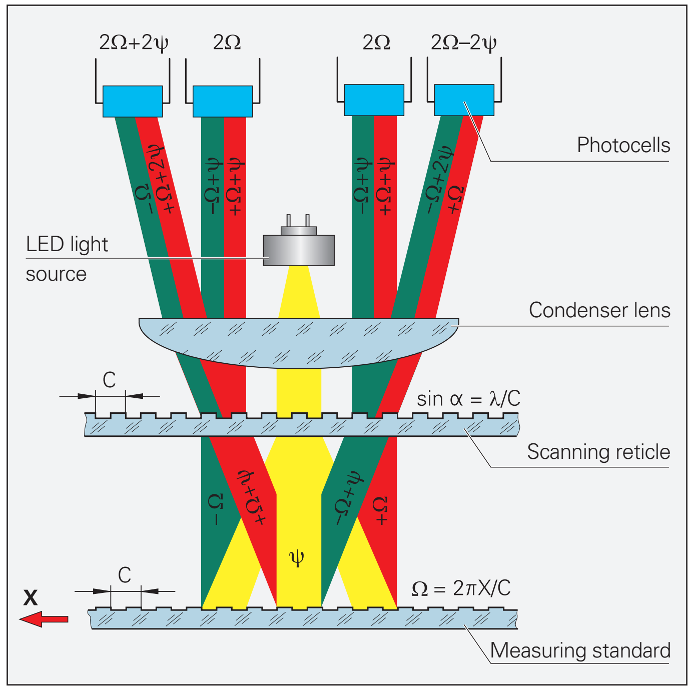
When a light wave passes through the scanning reticle, it is diffracted into three partial waves of the orders +1, 0, and –1, with nearly equal luminous intensity. The waves are diffracted by the scale such that most of the luminous intensity is found in the reflected diffraction orders +1 and –1. These partial waves meet again at the phase grating of the scanning reticle, where they are diffracted again and interfere. This produces essentially three waves that leave the scanning reticle at different angles. Photocells convert these alternating light intensities into electrical signals.

When there is relative motion between the scale and the scanning reticle, the diffracted wavefronts undergo a phase shift: movement by the amount of one grating period shifts the positive first-order diffraction wavefront by one wavelength in the positive direction, while the negative first-order diffraction wavefront is displaced by one wavelength in the negative direction. Since the two waves interfere with each other upon exiting the phase grating, these waves are shifted relative to each other by two wavelengths. This results in two signal periods when there is relative motion of just one grating period.

Interferential encoders use grating periods of, for example, 8 µm, 4 µm, or finer. Their scanning signals are largely free of harmonics and can be highly interpolated. These encoders are therefore especially well suited for small measuring steps and high accuracy.

Sealed linear encoders that use the interferential scanning principle are given the designation LF.

Interferential scanning principle (optics schematics)
C Grating period
ψ Phase shift of the light wave when passing through the scanning reticle
Ω Phase shift of the light wave due to motion X of the scale



Measuring accuracy

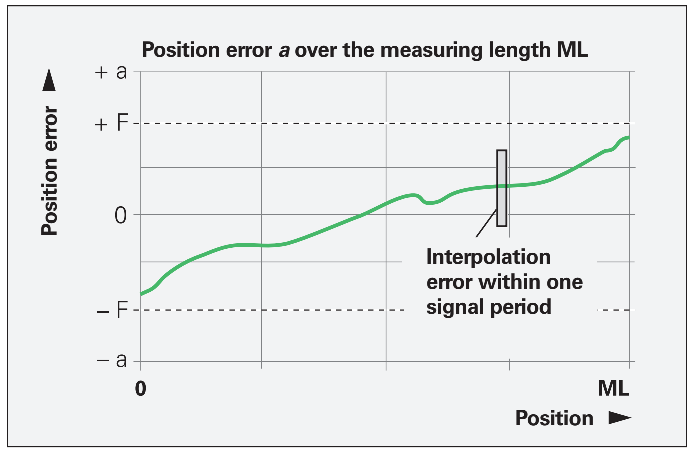
The accuracy of the linear measurement is mainly determined by
- The quality of the scale grating
- The quality of the scanning process
- The quality of the signal processing electronics
- The error from the scanning unit guideway to the scale

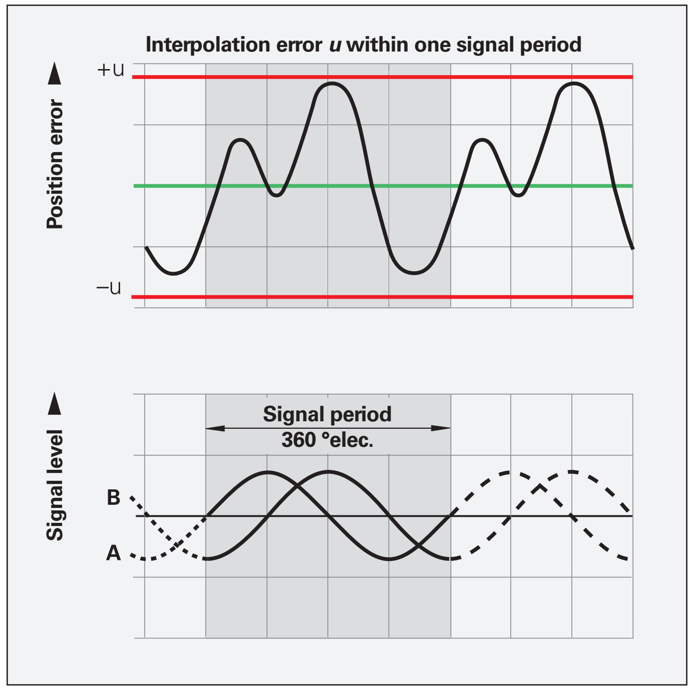
A distinction is made between position errors over relatively large paths of traverse—for example the entire measuring length—and interpolation errors within one signal period.

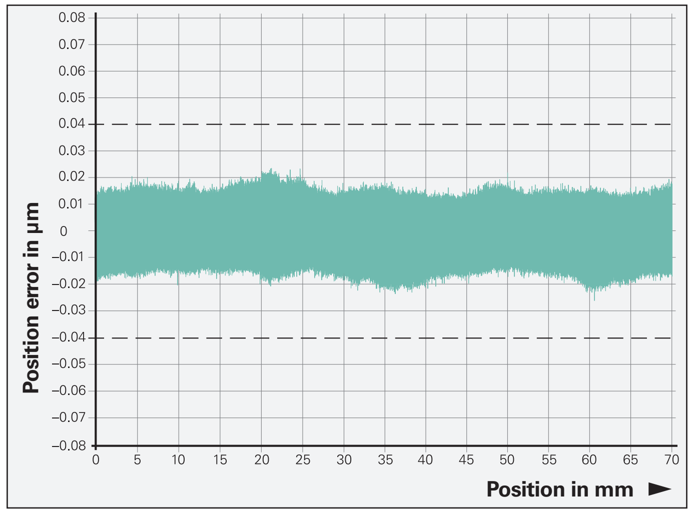
Position error over the measuring range
The accuracy of sealed linear encoders is specified in grades, which are defined as follows:
The extreme values ±F of the measuring curves over any max. one-meter section of the measuring length lie within the accuracy grade ±a. They are measured during the final inspection and documented in the calibration chart.

For sealed linear encoders, this data refers to the scale including the scanning unit, which is then the system accuracy.

Interpolation error within one signal period
The interpolation error within one signal period is determined by the signal period of the encoder, as well as the quality of the graduation and the scanning thereof. At any measuring position, it typically lies at ±2 % to ±0.5 % of the signal period (see *Selection guide, page 6*). The smaller the signal period, the smaller the interpolation error within one signal period. It is of critical importance both for accuracy of a positioning movement as well as for velocity control during the slow and even traverse of an axis, and therefore for surface quality and the quality of the machined part.







Interpolation error within one signal period for a measuring range of 70 mm for LF encoders

All HEIDENHAIN linear encoders are inspected before shipping for positioning accuracy and proper function.

The position errors are measured by traversing in both directions, and the averaged curve is shown in the calibration chart.

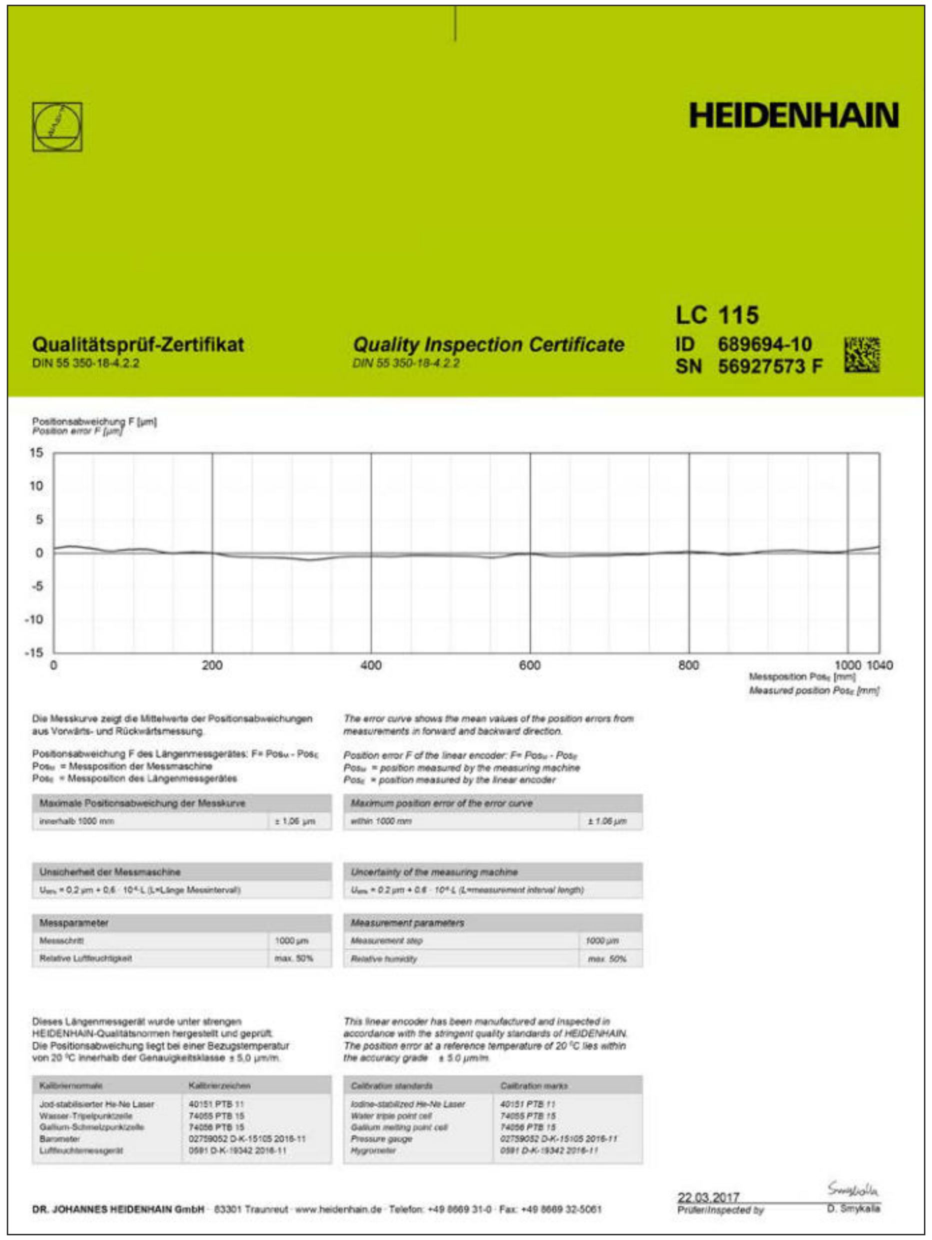
The **Quality Inspection Certificate** confirms the specified system accuracy of each encoder. The **calibration standards** ensure traceability to recognized national or international standards, as required by EN ISO 9001.

For the LC, LF, and LS series listed in this brochure, a calibration chart documents the **position error** ascertained for the measuring length. It also specifies the measuring parameters and the measurement uncertainty.

Temperature range
The linear encoders are inspected at a **reference temperature** of 20 °C. The system accuracy documented in the calibration chart is valid at this temperature.

The **operating temperature range** states the limits of ambient temperature within which the linear encoder will function properly.

The **storage temperature range** of –20 °C to +70 °C applies when the unit remains in its packaging. Starting from a measuring length of 3240 mm, the permissible storage temperature range for the LC 1x5 encoders is limited to –10 °C to +50 °C.



Example

Mechanical design types and mounting guidelines

Linear encoders with small cross section

The LC, LF, and LS slimline linear encoders should be mounted on a machined surface over the entire length—particularly for high dynamic requirements. Larger measuring lengths and a higher vibration load capacity can be achieved by using a mounting spar or clamping elements (only for LC 4x5).

The slimline linear encoders feature identical mounting dimensions. This makes it possible, for example, to exchange an incremental LS or LF for an absolute LC on a specific machine design (please note that the measuring length of the LF is smaller by 20 mm than that of the LC or LS). In addition, the same mounting spars can also be used, regardless of the encoder version (LC, LF, or LS).

The encoder is mounted such that the sealing lips are directed downward or away from splashing water (also see *General information on page 18*).

Thermal characteristics
Because they are rigidly fastened using two M8 screws, the linear encoders largely adapt themselves to the mounting surface. When fastened over the mounting spar, the encoder is fixed at its midpoint to the mounting surface. The flexible fastening elements ensure reproducible thermal behavior.

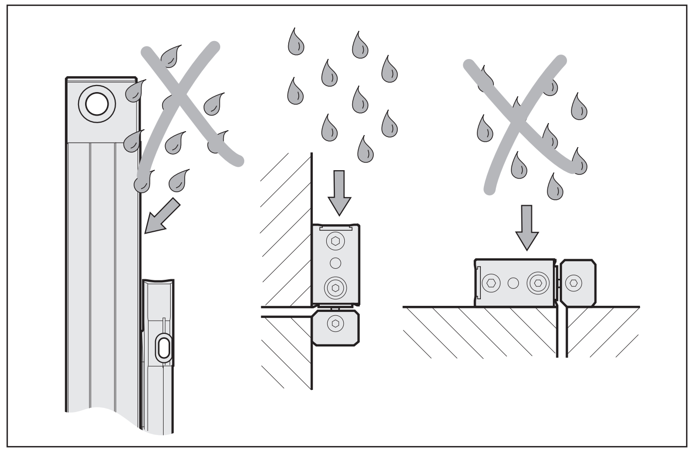
The **LF 485** with its graduation carrier of steel has the same coefficient of thermal expansion as a mounting surface of gray cast iron or steel.

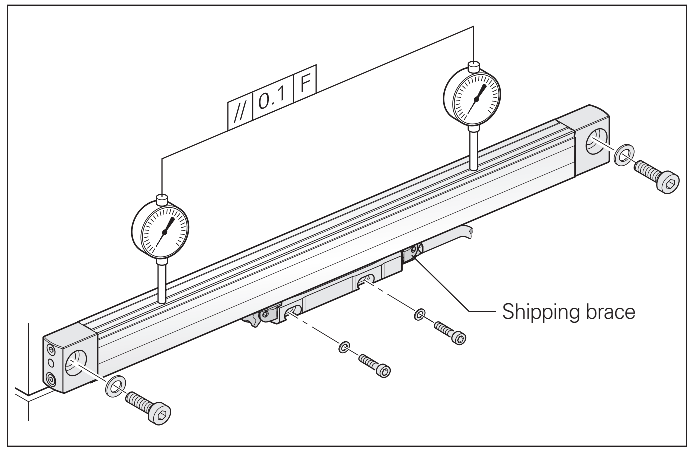
Mounting
It is surprisingly simple to mount the sealed linear encoders from HEIDENHAIN: you need only align the scale unit at several points along the machine guideway. Stop surfaces or stop pins can also be used for this. The shipping brace already sets the proper gap between the scale unit and the scanning unit, as well as the lateral tolerance. If the shipping brace needs to be removed before mounting due to a lack of space, then the mounting gauge is used to set the gap between the scale unit and the scanning unit easily and exactly. Lateral tolerances must also be maintained.

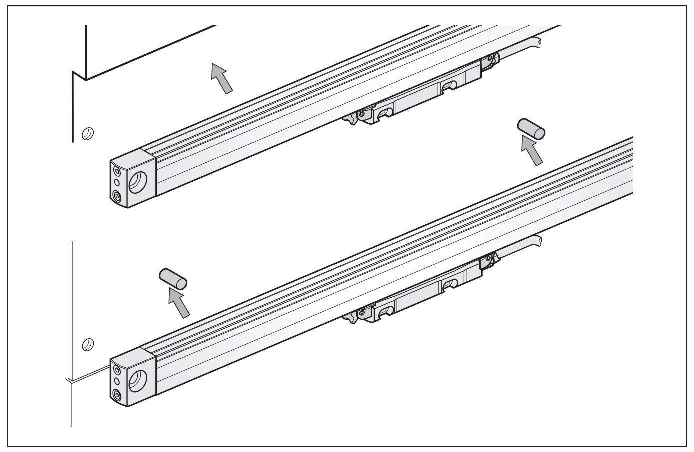
LF 485

LC 415

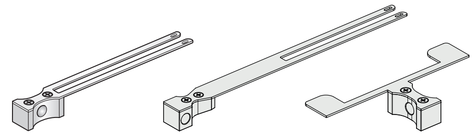
LS 487







Accessory:
Mounting and test gauges for slimline linear encoders
The **mounting gauge** is used to set the gap between the scale unit and the scanning unit if the shipping brace needs to be removed before mounting. The **test gauges** are used to quickly and easily check the gap of the mounted linear encoder.



	ID		
Mounting gauge 1.0 mm (gray)	737748-01	1211268-01	1211239-01
Test gauge max.1.3 mm (red)	737748-02	1211268-02	1211239-02
Test gauge min. 0.7 mm (blue)	737748-03	1211268-03	1211239-03

Along with the standard procedure of using two M8 screws to mount the scale unit on a plane surface, there are also other mounting possibilities:

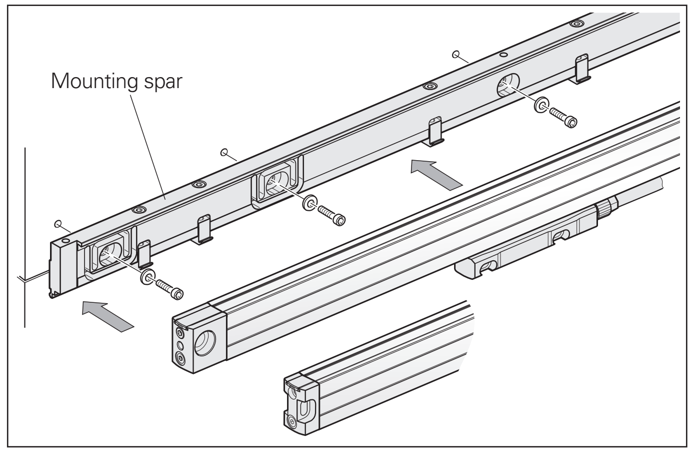
Installation with mounting spar
Mounting the encoder with a mounting spar can be especially beneficial. The mounting spar can be fastened as part of the machine assembly process. The encoder is then simply clamped on during final mounting. Easy exchange also facilitates servicing. HEIDENHAIN recommends mounting with the mounting spar when measuring lengths are greater than 620 mm and dynamic requirements are high. The mounting spar is always required for measuring lengths greater than 1240 mm.

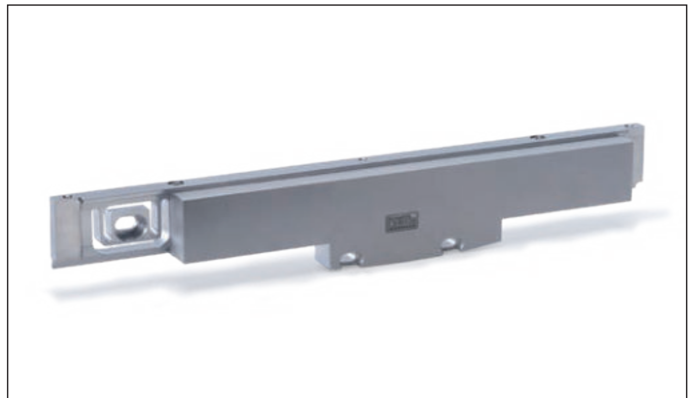
For the **MSL 41 mounting spar**, the components required for clamping are already preassembled. This mounting spar is designed for linear encoders with normal or short end blocks. The LC 4x5, LF 4x5, and LS 4x7 can be mounted by either side to enable a cable outlet at either end. The MSL 41 mounting spar must be ordered separately.

The **mounting aid** is locked onto the mounted spar and therefore simulates an optimally mounted scanning unit. The customer's fastening for the scanning unit can be easily aligned to it. Then the mounting aid is replaced by the linear encoder.

Accessory:
MSL 41 mounting spar
ID 770902-xx

Mounting aid for scanning unit
ID 753853-01

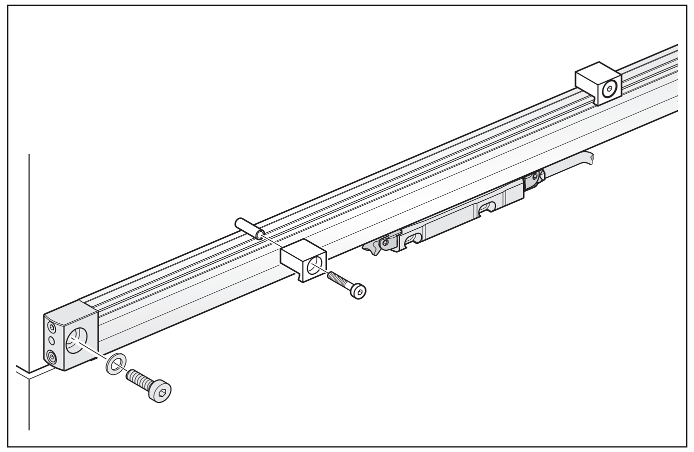




Mounting aid fastened to a mounting spar

Mounting with clamping elements
If the cable outlet is to the right, the LC 4x5 scanning unit, which is fastened by its end blocks, can additionally be fixed by clamping elements. This eliminates the need of a mounting spar for measuring lengths greater than 620 mm.

Accessory:
Clamping elements
With pin and M5x10 screw
ID 556975-01 (10 per package)



Linear encoders with large cross section

The LB, LC, LF, and LS full-size linear encoders are fastened over their entire length onto a machined surface. This gives them a **high vibration rating**. The oblique arrangement of the sealing lips permits **universal mounting** with vertical or horizontal scale housing with equally high protection rating.

The LC 1x5 features an optimized sealing system with two successive pairs of sealing lips. When cleaned compressed air is introduced into the scale housing, it effectively seals the two pairs of sealing lips against ambient air. This optimally protects the interior of the encoder from contamination.

The flow rate is set through a connecting piece with integrated throttle (see separate accessories under *Protection*, page 18).

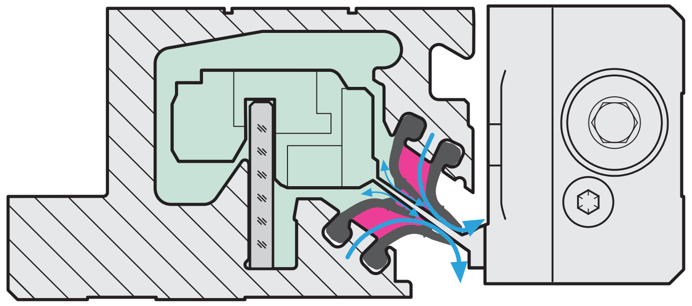
Thermal characteristics
The thermal behavior of the LB, LC, LF, and LS 100 full-size linear encoders has been optimized:

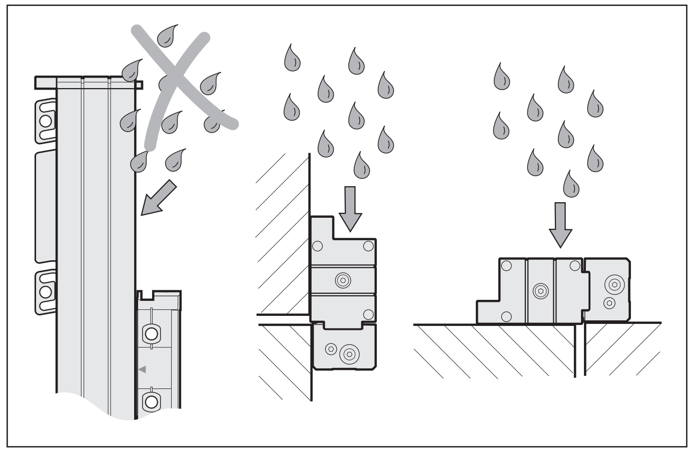
On the **LF**, the steel scale is cemented to a steel carrier that is fastened directly to the machine element.

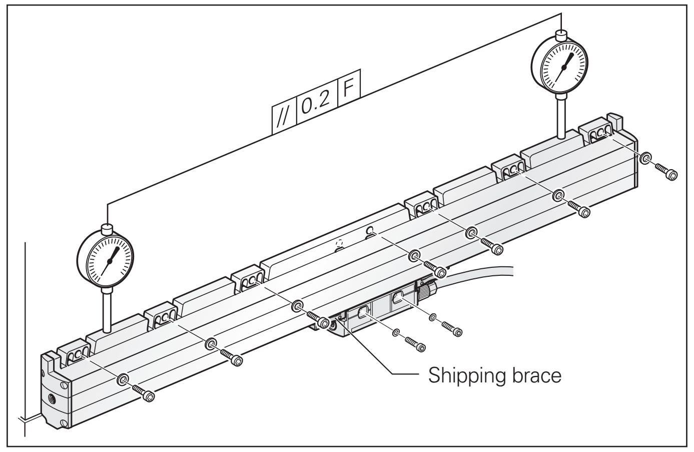
For the multi-section **LC 200** and **LB**, the steel scale tape is clamped directly onto the machine element. In this way, the encoders are subject to the same thermal changes in length as the bearing surface.

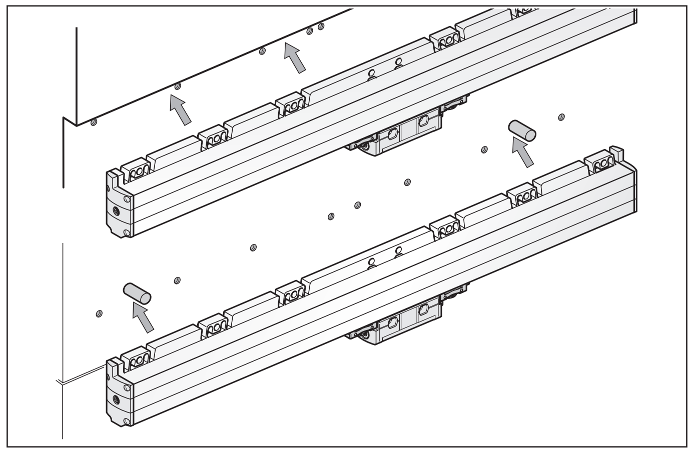
The **LC** and **LS** are fixed to the mounting surface at their midpoint. The flexible fastening elements permit reproducible thermal behavior.

Mounting
It is surprisingly simple to mount the sealed linear encoders from HEIDENHAIN: you need only align the scale unit at several points along the machine guideway. Stop surfaces or stop pins can also be used for this. The shipping brace already sets the proper gap between the scale unit and the scanning unit. The lateral gap is to be set during mounting. If the shipping brace needs to be removed before mounting due to a lack of space, then the mounting gauge is used to set the gap between the scale unit and the scanning unit easily and exactly. Lateral tolerances must also be maintained.


Sealing system of the LC 1x5







Mounting the multi-section LC 2x1 and LB 382
The LC 2x1 and LB 382 with measuring lengths over 3240 mm are mounted on the machine in individual sections:
- Mount and align the individual housing sections
- Pull in the scale tape over the entire length and tension it
- Lubricate the sealing lips and pull them in
- Insert the scanning unit

Adjustment of the scale tape tension enables linear machine error compensation up to ±100 µm/m.

Accessory:
Mounting aids

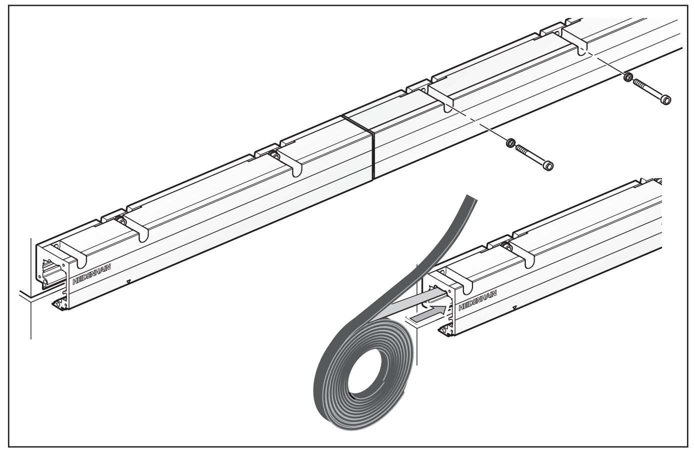
For LC 1x3, LS 1x7	ID 547793-02
For LC 1x5	ID 1067589-02
For LC 2x1, LB 382	ID 824039-01

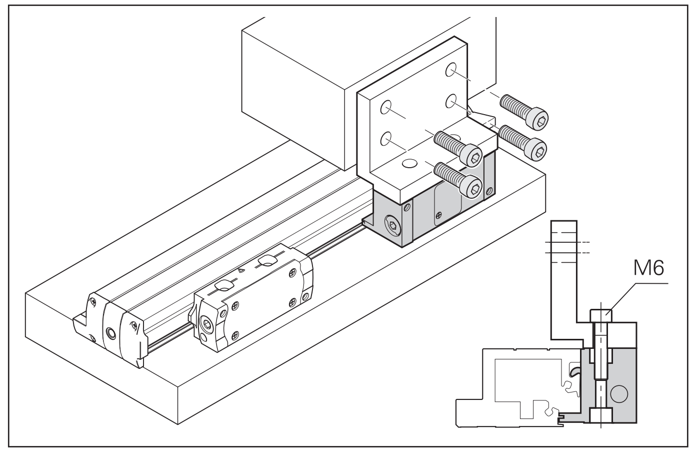
The mounting aid is locked onto the scale unit, simulating an optimally adjusted scanning unit. The customer's fastening for the scanning unit can be easily aligned to it. The mounting aid is then removed and the scanning unit is attached to the mounting bracket.

Accessory:
Mounting and test gauges for full-size linear encoders

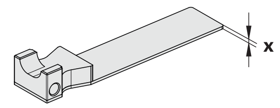
The **mounting gauge** is used to set the gap between the scale unit and the scanning unit if the shipping brace needs to be removed before mounting. The **test gauges** are used to quickly and easily check the gap of the mounted linear encoder.

Accessory:
Lubricating device
For LC 2x1, LB 382 sealing lips
ID 1104590-05





Example



	LC 1xx, LS 1xx		LB 382/LC 2x1	
	x	ID	x	ID
Mounting gauge (gray)	1,5 mm	575832-11	1,0 mm	772141-11
Test gauge max. (red)	1,8 mm	575832-12	1,3 mm	772141-12
Test gauge min. (blue)	1,2 mm	575832-13	0,7 mm	772141-13