Technical Information

Encoders for Linear Motors in the Electronics Industry

The semiconductor industry and automation technology increasingly require more precise and faster machines in order to satisfy growing demands on miniaturization, quality, and manufacturing cost reduction. Linear motors are gradually becoming more important in such highly-dynamic applications with one or more feed axes. The benefits of this direct drive technology are low wear, low maintenance, and higher productivity.

However, this increase in productivity is possible only if the control, the motor, the machine frame, and the position encoder are optimally adjusted to one another. Direct drives place rigorous demands on the quality of the measuring signals.
Optimum measuring signals
- reduce vibration in the machine frame,
- stop excessive noise exposure from velocity-dependent motor sounds, and
- prevent additional heat generation,
- so allowing the motor to realize its maximum mechanical power rating.

The efficiency of a linear motor is therefore greatly influenced by the selection of the position encoder. Encoders with optical scanning methods provide benefits in the accuracy, speed stability, and thermal behavior of a direct drive. HEIDENHAIN offers a wide range of linear encoders with technical characteristics specifically designed for linear motors in the electronics industry.

Design of direct drives
The decisive advantage of direct drive technology is the very stiff coupling of the drive to the feed component without any other mechanical transfer elements. This allows significantly higher gain in the control loop than with a conventional drive.

Velocity measurement on direct drives
On direct drives there is no additional encoder for measuring the speed. Both the position and speed are measured by the position encoder: linear encoders for linear motors, angle encoders for rotating axes. Since there is no mechanical transmission between the speed encoder and the feed unit, the position encoder must have a correspondingly high resolution in order to enable exact velocity control at slow traversing speeds. The velocity is calculated from the distance traversed per unit of time. This method—which is also applied to conventional axes—represents a numerical differentiation that amplifies periodic disturbances or noise in the signal. The combination of significantly higher control loop gain, as is used particularly with direct drives, and insufficient encoder signal quality can result in a dramatic decline in drive performance.

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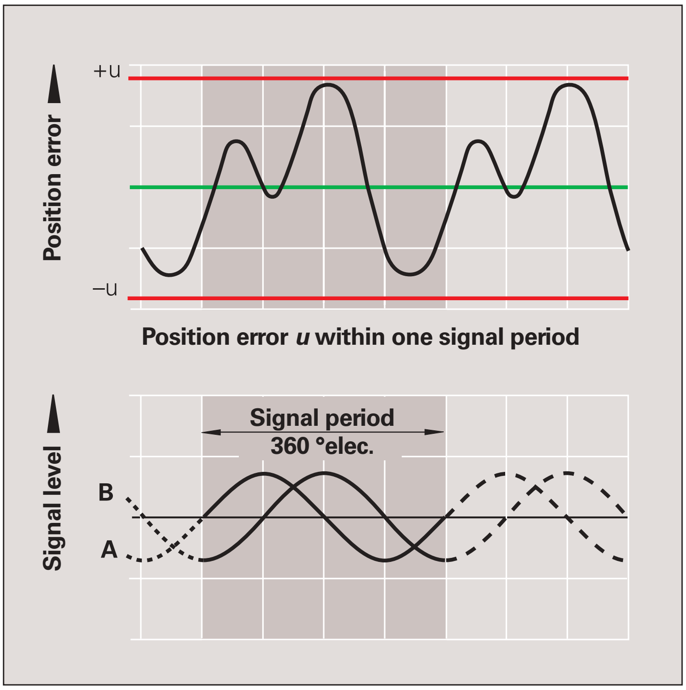
Requirements and Effects

Signal quality of position encoders
Modern encoders feature either an incremental, which means counting, or an absolute method of position measurement. The path information is transformed in the encoder into two sinusoidal signals with 90° phase shift. Both methods require that the sinusoidal scanning signals be interpolated in order to attain a sufficiently high resolution. Inadequate scanning, contamination of the measuring standard, and insufficient signal processing can lead to a deviation from the ideal sinusoidal shape. As a consequence, during interpolation periodic position error occurs within one signal period of the encoder's output signals. These position errors within one signal period are referred to as "interpolation error." On high-quality encoders it is typically 1% to 2% of the signal period.



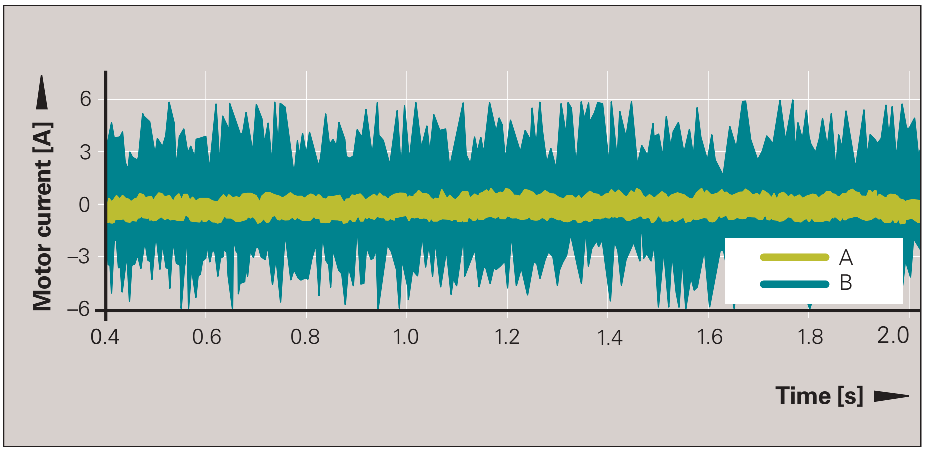
Effects of interpolation error
Generation of heat and noise
If the frequency of the interpolation error increases, the feed drive can no longer follow the error curve. However, the current components generated by the interpolation error cause increased motor noises and additional heating of the motor.

A comparison of the effects of linear encoders with low and high interpolation error on a linear motor illustrates the significance of high-quality position signals. The LIDA linear encoder used here generates only barely noticeable disturbances in the motor current: the motor operates normally and develops little heat.

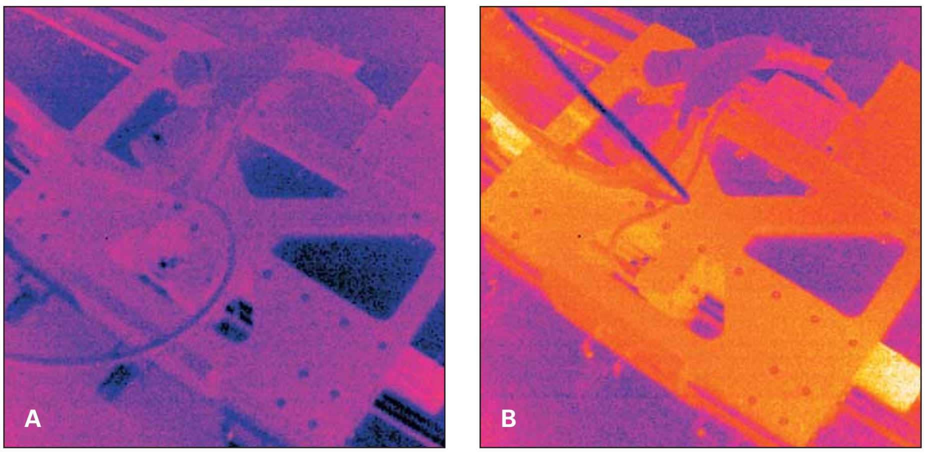
If at the same controller setting, the interpolation errors of the same encoder are increased through poor adjustment, significant noise arises in the motor current. This causes an increased amount of noise and heat generated in the motor.

Dynamic behavior
Digital filters are often used with direct drives to smooth the position signals. However, the additional phase delay caused by filtering in the speed-control loop must be kept to a minimum, otherwise the dynamic accuracy decreases.

Position encoders with optimum signal quality help to reduce the use of filters, meaning that the control bandwidth is maintained.



Motor current of a direct drive with position encoder
A: With low interpolation error
B: With high interpolation error



Heat generation of a linear motor controlled with an encoder
A: With low interpolation error
B: With high interpolation error

Position encoders for direct drives
Linear encoders that generate a high-quality position signal with low interpolation errors are essential for optimal operation of direct drives in the electronics industry. Encoders that use photoelectric scanning are ideally suited for this task, since very fine graduations can be scanned by this method.

Encoders with optical scanning therefore play a significant role in exploiting the potential of direct drives.

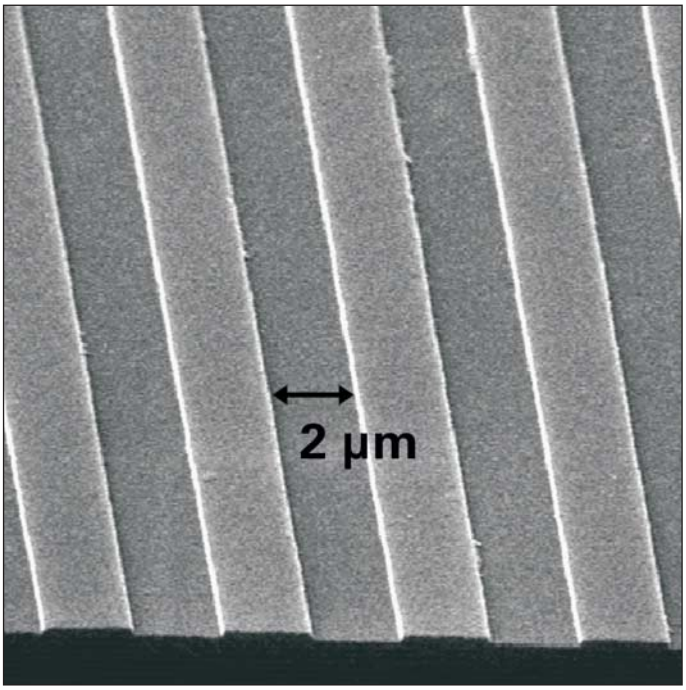
Exact graduations
HEIDENHAIN encoders with optical scanning incorporate measuring standards of periodic structures known as graduations. The substrate material is glass, steel, or—for large measuring lengths—steel strips. These fine graduations—graduation periods from 40 µm to under 1 µm are typical—are manufactured in a photolithographic process. They are characterized by high edge definition and excellent homogeneity—a fundamental prerequisite for low interpolation error, and therefore for smooth operating performance and high control loop gain.

Durable measuring standards
By the nature of their design, the measuring standards of exposed linear encoders are less protected from their environment. HEIDENHAIN therefore always uses tough gratings manufactured in special processes.

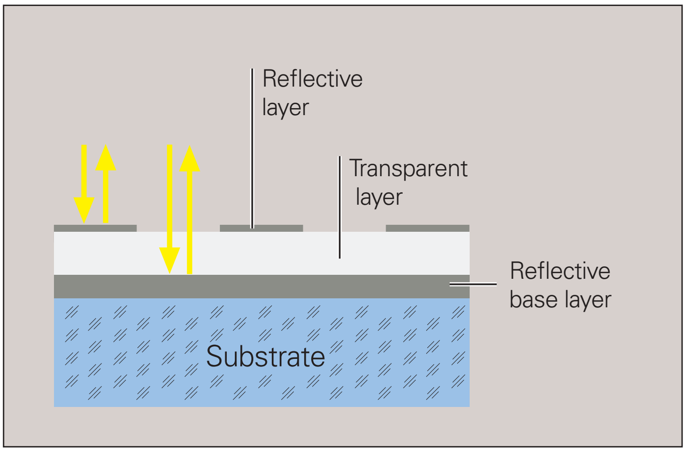
In the DIADUR process, hard chrome structures are applied to a glass or steel carrier. The AURODUR process applies gold to a steel strip to produce a scale tape with a hard gold graduation.

In the SUPRADUR process, a transparent layer is applied first over the reflective primary layer. Then an extremely thin, hard chrome layer is applied to produce a grating. Scales with SUPRADUR graduations have proven to be particularly insensitive to contamination because the low height of the structure leaves practically no surface for dust, dirt or water particles to accumulate.

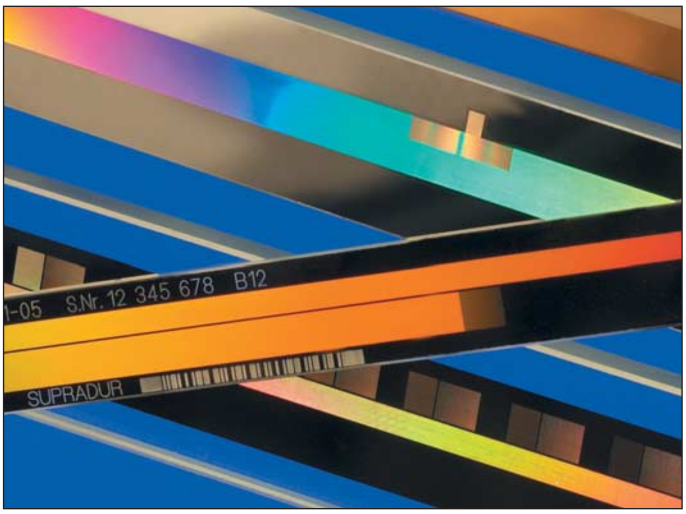
In this way, HEIDENHAIN production technologies ensure an enduringly high signal quality that promotes the use of direct drives for particularly demanding applications.



DIADUR phase grating with approx. 0.25 µm grating height



SUPRADUR process: Optical three-dimensional graduation structure



Optimized scanning methods
The scanning method and the high quality of the grating share responsibility for low interpolation error. An especially beneficial feature is the single-field scanning with which the exposed linear encoders from HEIDENHAIN operate: The output signals are generated from only one scanning field. This large scanning field, and the special optical filtering through the structure of the scanning reticle and photosensor, generate scanning signals with constant signal quality over the entire range of traverse. This is the prerequisite for:

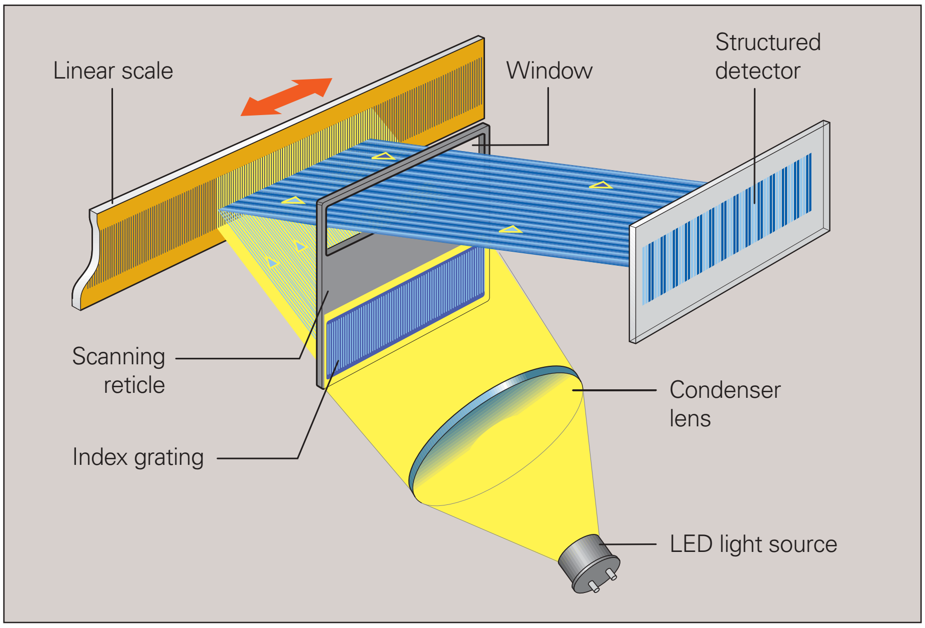
- Low signal noise
- Low interpolation error
- High traversing speed
- Good control loop performance for direct drives
- Low heat generation of the motor

Signal generation based on the imaging scanning principle (LIDA 400)
To put it simply, the imaging scanning principle functions by means of projected-light signal generation: two scale gratings with equal grating periods are moved relative to each other—the scale and the scanning reticle. The carrier material of the scanning reticle is transparent, whereas the graduation on the measuring standard may be applied to a transparent or reflective surface.

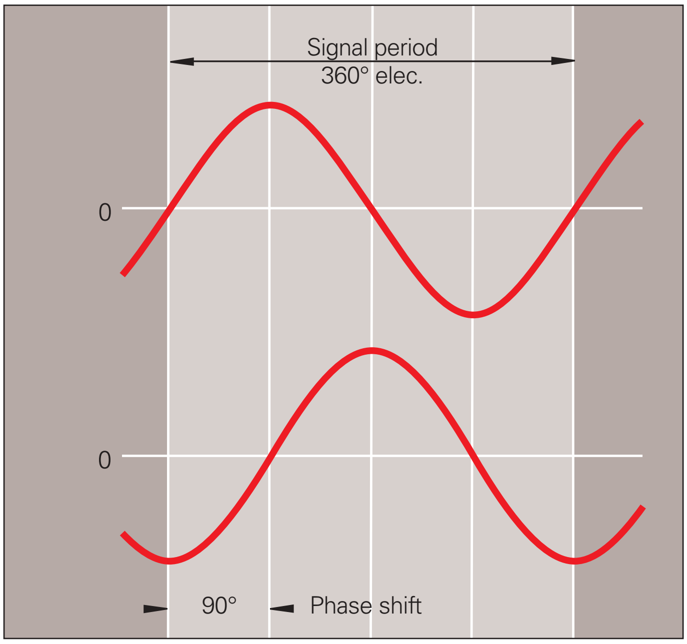
When parallel light passes through a grating, light and dark surfaces are projected at a certain distance. An index grating with the same grating period is located here. When the two gratings move in relation to each other, the incident light is modulated: if the gaps are aligned, light passes through. If the lines of one grating coincide with the gaps of the other, no light passes through. Photovoltaic cells convert these variations in light intensity into electrical signals. The specially structured grating of the scanning reticle filters the light current to generate nearly sinusoidal output signals.

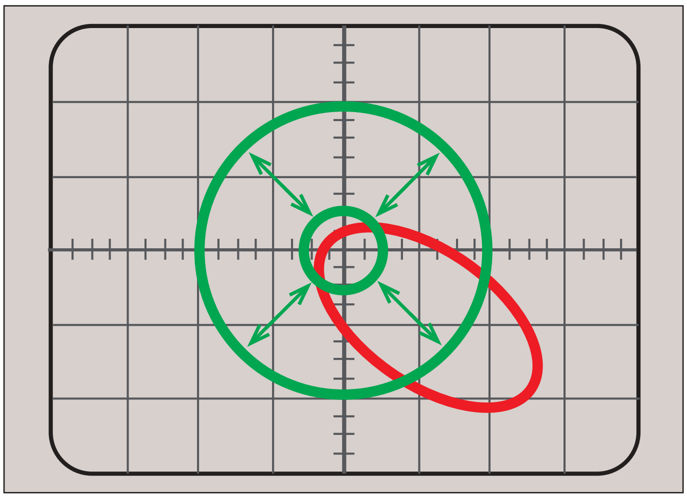
In the XY representation on an oscilloscope the signals form a Lissajous figure. Ideal output signals appear as a concentric inner circle. Deviations in the circular form and position are caused by position error within one signal period and therefore go directly into the result of measurement. The size of the circle, which corresponds to the amplitude of the output signal, can vary within certain limits without influencing the measuring accuracy.

On direct drives, deviations from the circular form cause acoustic noise, reduce control quality and increase heat generation.



Photoelectric scanning in accordance with the imaging principle with steel scale tape and single-field scanning (LIDA 400)





Lower sensitivity to contamination
Production facilities and handling devices for the semiconductor industry demand high acceleration and compact designs. Such requirements call specifically for exposed measuring systems that operate without friction and, because they can operate without their own housing, can be designed to be very small and therefore low in mass. Special scanning methods and production techniques are used to provide tough protection against contamination even without sealing the encoder.

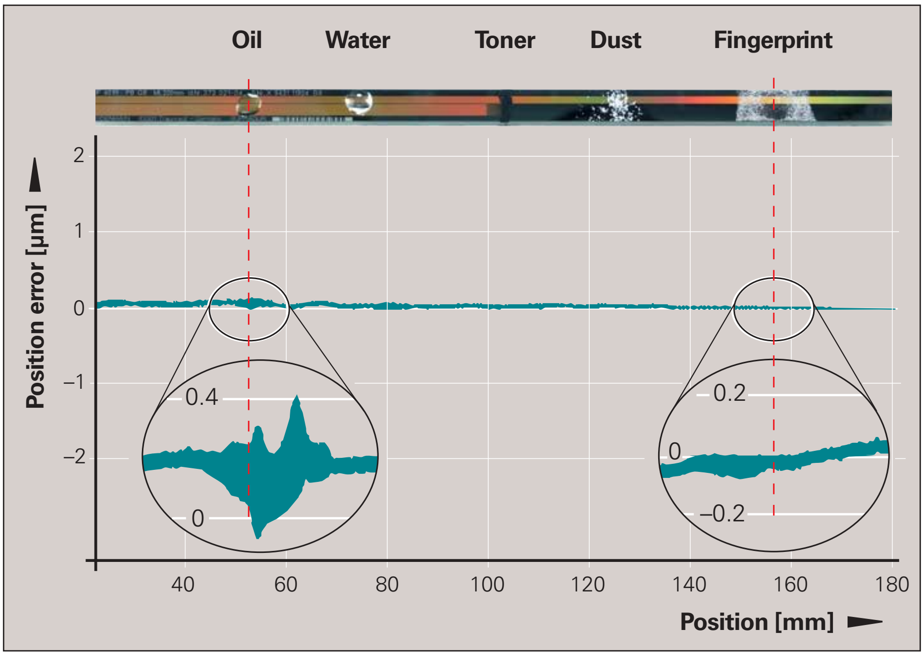
Exposed linear encoders from HEIDENHAIN operate with **single-field scanning.** Only one scanning field is used to generate the scanning signals. Local contamination on the measuring standard (e.g., fingerprints from mounting or oil accumulation from guideways) influences the light intensity of the signal components, and therefore of the scanning signals, in equal measure. The output signals do change in their amplitude, but not in their offset and phase position. They stay highly interpolable, and the interpolation error remains small.

The **large scanning field** additionally reduces sensitivity to contamination. In many cases this can prevent encoder failure. This is particularly clear with the LIDA 400 and LIF 400, which in relation to the grating period have a very large scanning surface of 14.5 mm^2. Even with contamination up to 3 mm in diameter, the encoders continue to provide high-quality signals. The position error remains far below the values specified for the accuracy grade of the scale.

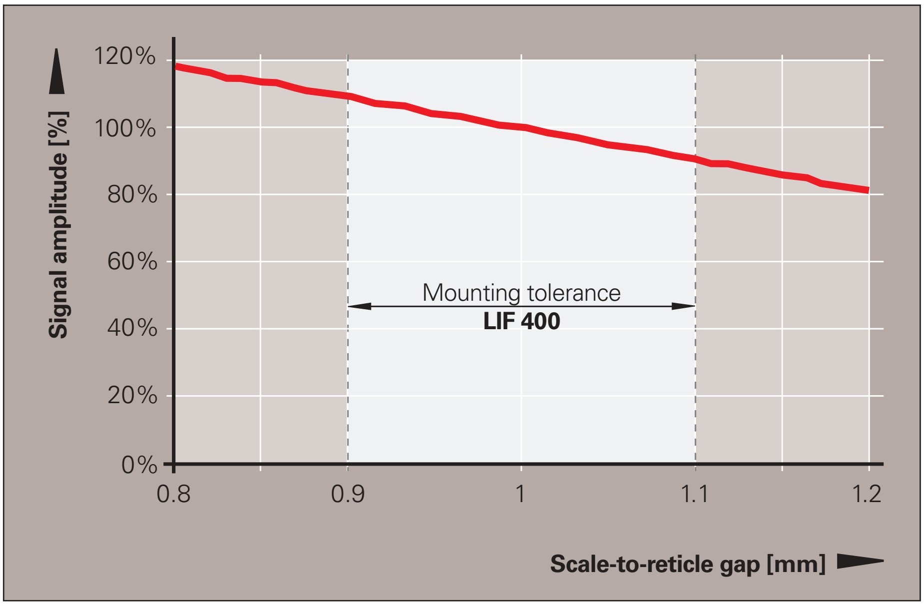
An essential prerequisite for optical encoders with low sensitivity to contamination is therefore an optimized scanning method, the large scanning field, and the contamination-tolerant graduation.

Application-oriented mounting tolerances
Very small signal periods usually come with very narrow distance tolerances between the scanning head and scale tape. Thanks to the interferential scanning principle of the LIF 400 and innovative index gratings, such as in the LIDA 400, it has become possible to provide ample mounting tolerances in spite of the small signal periods. Within the mounting tolerances, therefore, changes in the signal amplitude remain negligible.

This behavior is substantially responsible for the high reliability of exposed linear encoders from HEIDENHAIN.



Reaction of the LIF 400 to contamination



Position Encoders for Linear Motors

Exposed linear encoders from HEIDENHAIN are optimized for use on fast, precise machines as sought by the semiconductor industry and automation technology. In spite of the exposed mechanical design they are highly tolerant to contamination, ensure high long-term stability, and are fast and simple to mount. Their low weight and compact design suit encoders of the LIF ①, LIP ② and LIDA ③ series particularly for linear motors.

Application	Signal period	Max. interpolation error	Interface	Model
For very high accuracy	0.128 µm	• 0.001 µm	⊓⊔TTL	LIP 372
			∼ 1 V_{PP}	LIP 382
	2 µm	• 0.02 µm	⊓⊔TTL	LIP 471
			∼ 1 V_{PP}	LIP 481
	4 µm	• 0.04 µm	⊓⊔TTL	LIP 571
			∼ 1 V_{PP}	LIP 581
• For simple installation • With limit switches and homing track	4 µm	• 0.04 µm	⊓⊔TTL	LIF 471
			∼ 1 V_{PP}	LIF 481
• For high traversing speed • Limit switches	20 µm	• 0.2 µm	⊓⊔TTL	LIDA 47x
			∼ 1 V_{PP}	LIDA 48x

HEIDENHAIN position encoders for direct drives (selection): Maximum values of interpolation error with respect to the signal period

HEIDENHAIN

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For more information:
- Brochure: *Exposed Linear Encoders*
- Technical Information: *Single-Field Scanning*

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