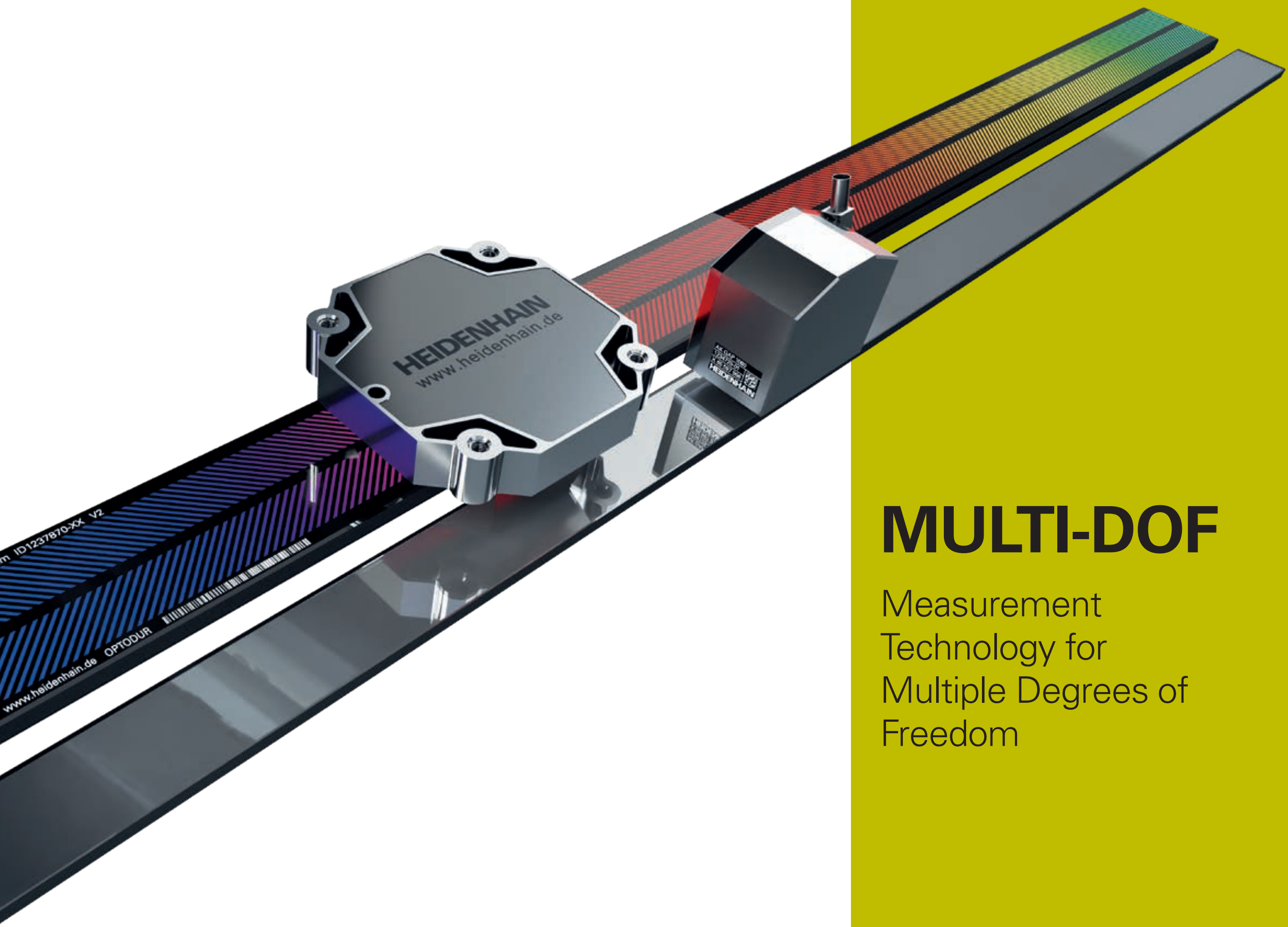
HEIDENHAIN



MULTI-DOF

Measurement Technology for Multiple Degrees of Freedom

12/2022

D*plus* encoders for perfect motion systems

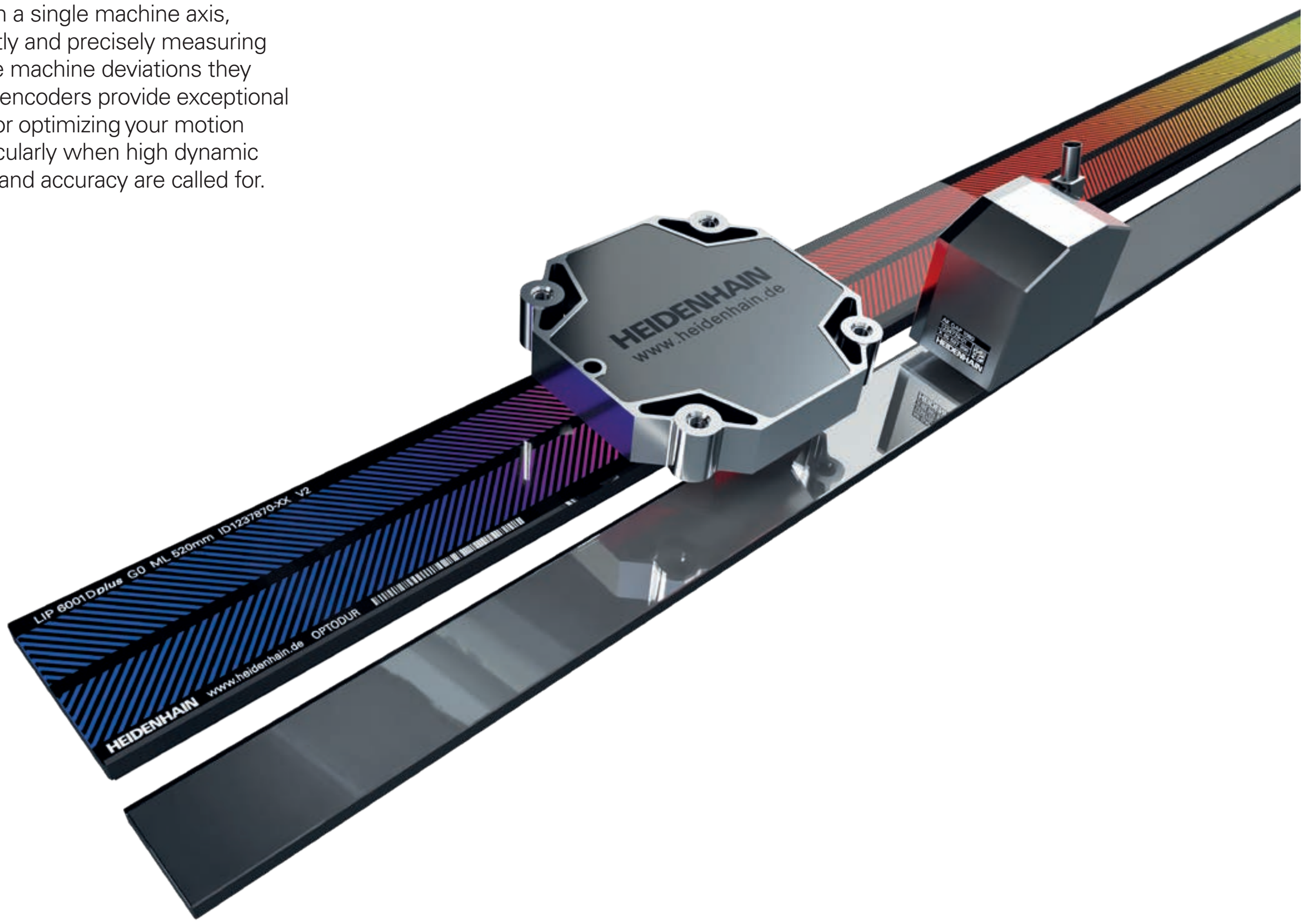
Linear encoders measure the position of linear axes without intervening mechanical elements, thereby eliminating multiple potential sources of error:
- Positioning error due to thermal changes in the recirculating ball screw
- Reversal error
- Kinematic error due to the ball-screw pitch error

As a result, linear encoders are essential components on machines requiring high **positioning accuracy** and **machining speed**.

D*plus* encoders
D*plus* encoders measure multiple degrees of freedom on a single machine axis, thereby directly and precisely measuring errors and the machine deviations they cause. D*plus* encoders provide exceptional possibilities for optimizing your motion system, particularly when high dynamic performance and accuracy are called for.

Exposed linear encoders are deployed on machines and automated systems requiring high measurement accuracy. Typical applications include the following:
- Production and measurement equipment in the semiconductor industry
- PCB assembly machines
- Ultra-precision equipment such as diamond lathes for optical components, facing lathes for magnetic storage disks and grinding machines for ferrite parts.
- High-accuracy machine tools
- Measuring machines, comparators, measuring microscopes, and other precision measuring devices
- Direct drive motors

Mechanical design
Exposed linear encoders consist of a scale or scale tape and a scanning head that operate without mechanical contact. The scales of exposed linear encoders are fastened to a mounting surface. High flatness of the mounting surface is thus an important requirement for the high accuracy of linear encoders.



Information about the following topics is available upon request or online at www.heidenhain.com:
- Angle encoders with integral bearing
- Modular angle encoders with optical scanning
- Modular angle encoders with magnetic scanning
- Rotary encoders
- Encoders for servo drives
- Linear encoders for numerically controlled machine tools
- Signal converters
- HEIDENHAIN controls

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 placed.

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

Further information:
For detailed descriptions of all available interfaces, as well as general electrical information, please refer to the *Interfaces of HEIDENHAIN Encoders* brochure (ID 1078628-xx).

For the required connecting cables, see the *Cables and Connectors* brochure (ID 1206103-xx).

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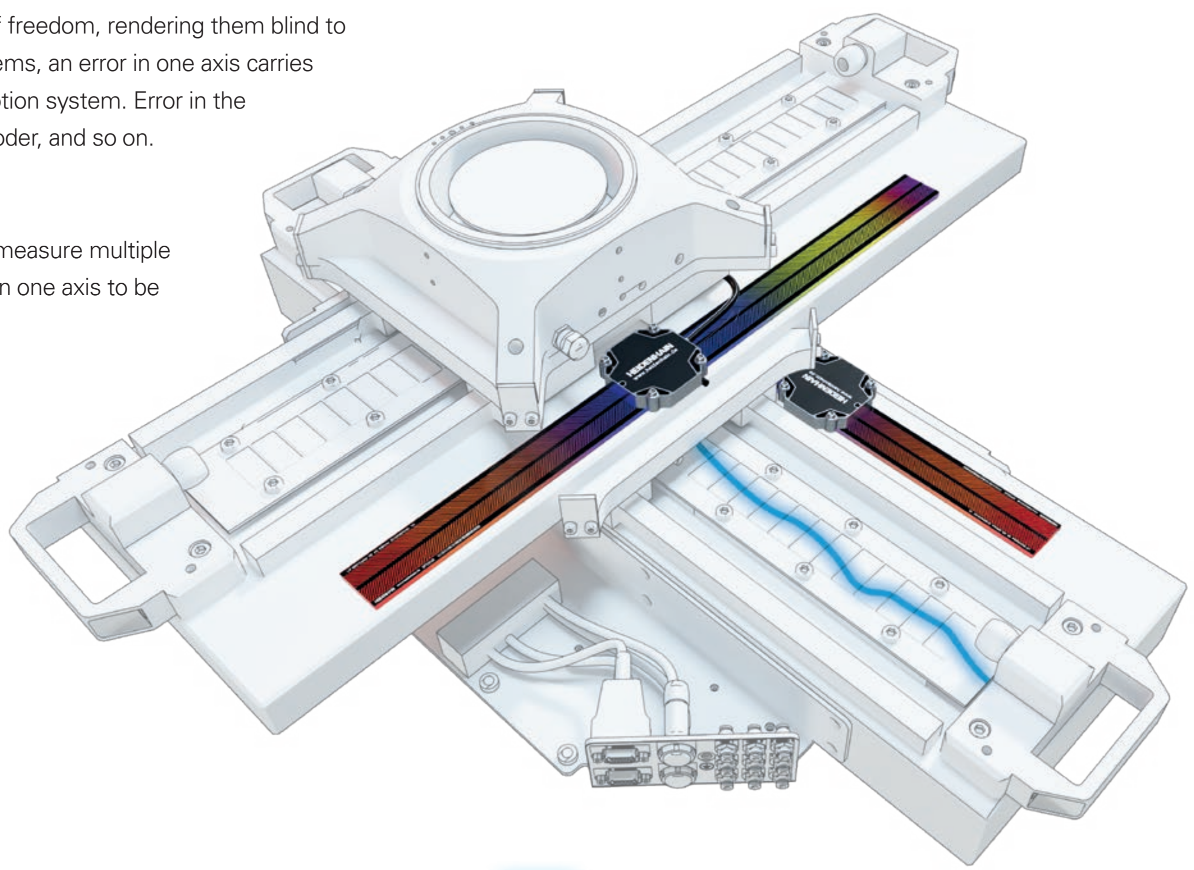
Multi-dimensional measurement technology

Conventional encoders can measure only one degree of freedom, rendering them blind to unavoidable errors in other directions. In multi-axis systems, an error in one axis carries over into the other axes, thereby affecting the entire motion system. Error in the first axis changes the actual position of the second encoder, and so on. Yet these errors are not normally measured.

The D*plus* encoders from HEIDENHAIN, however, can measure multiple degrees of freedom on a single axis, allowing the error in one axis to be measured and compensated for in the next.



= *Guideway error*

The accuracy of a motion system depends on multiple factors:

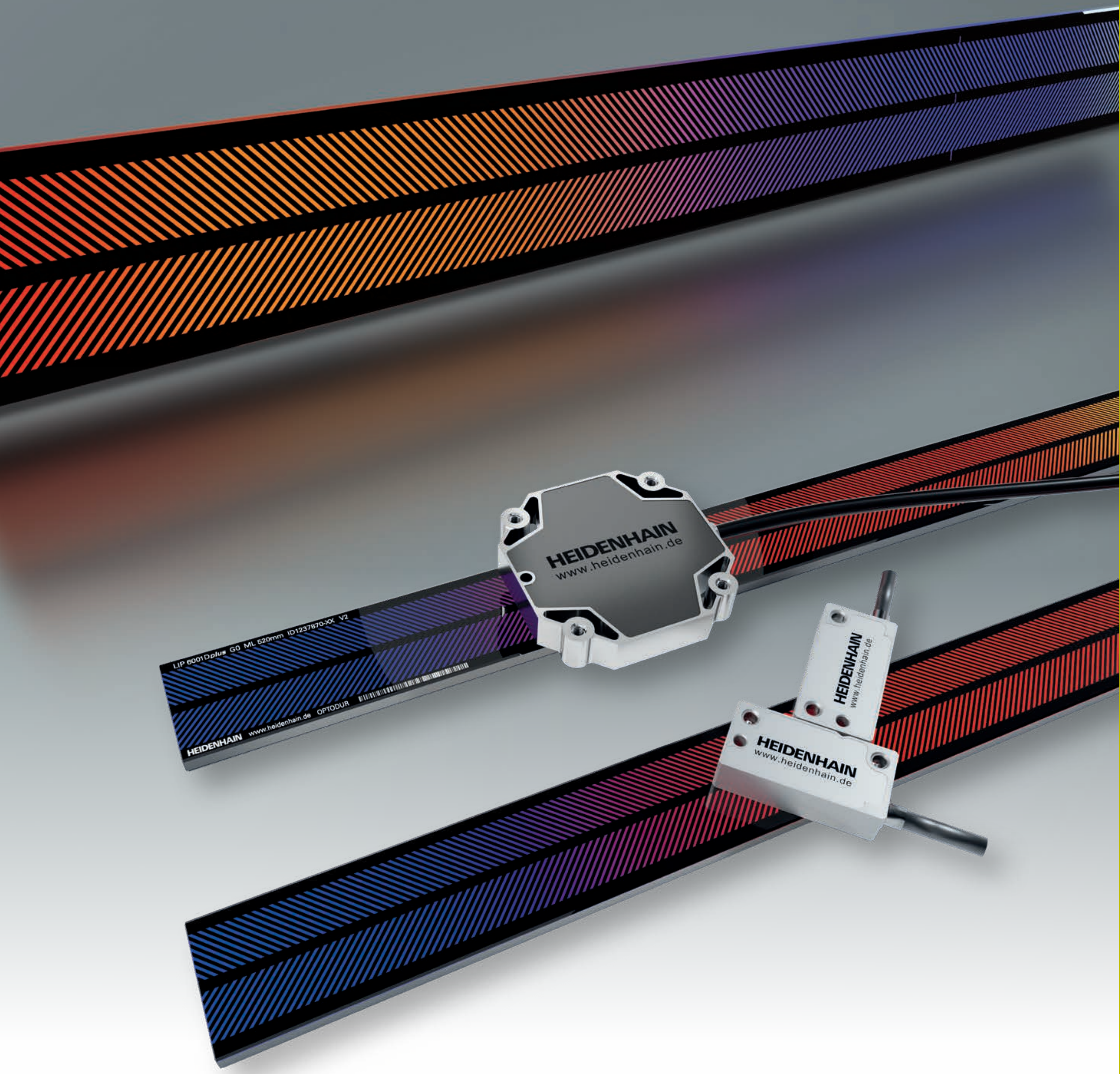
- Non-linear guideway errors
- Vertical flatness, horizontal straightness
- Pitch, yaw and roll
- Squareness error
- Kinematics error
- Thermal expansion and other thermal effects
- Hysteresis

Higher accuracy and greater dynamic performance

More than ever, productivity and accuracy are key competitive advantages. But faster and more precise production processes are only part of the equation: reproducibility and stable quality are essential as well. Attaining reliably high accuracy greatly expands your manufacturing capabilities, particularly in the high-end spectrum.

The challenge of perfecting position measurement in the primary axis is significant. Simply optimizing the scale and scanning head is not sufficient for maximizing a motion system's precision and dynamic performance. Machine design factors and thermal changes play a greater role as accuracy and dynamic-performance requirements increase. Thanks to multi-dimensional encoders such as the LIP 6000 D*plus*, these factors can be directly measured and compensated for.

Innovative graduation structures



Precise measurement for optimal performance

The interferential measuring principle generates signals by utilizing the refraction and interference of light on finely divided gratings. The measuring standard consists of a flat surface with 0.2 µm-high reflecting lines. These lines are read by a scanning reticle featuring a light-permeable phase grating with an identical graduation period.

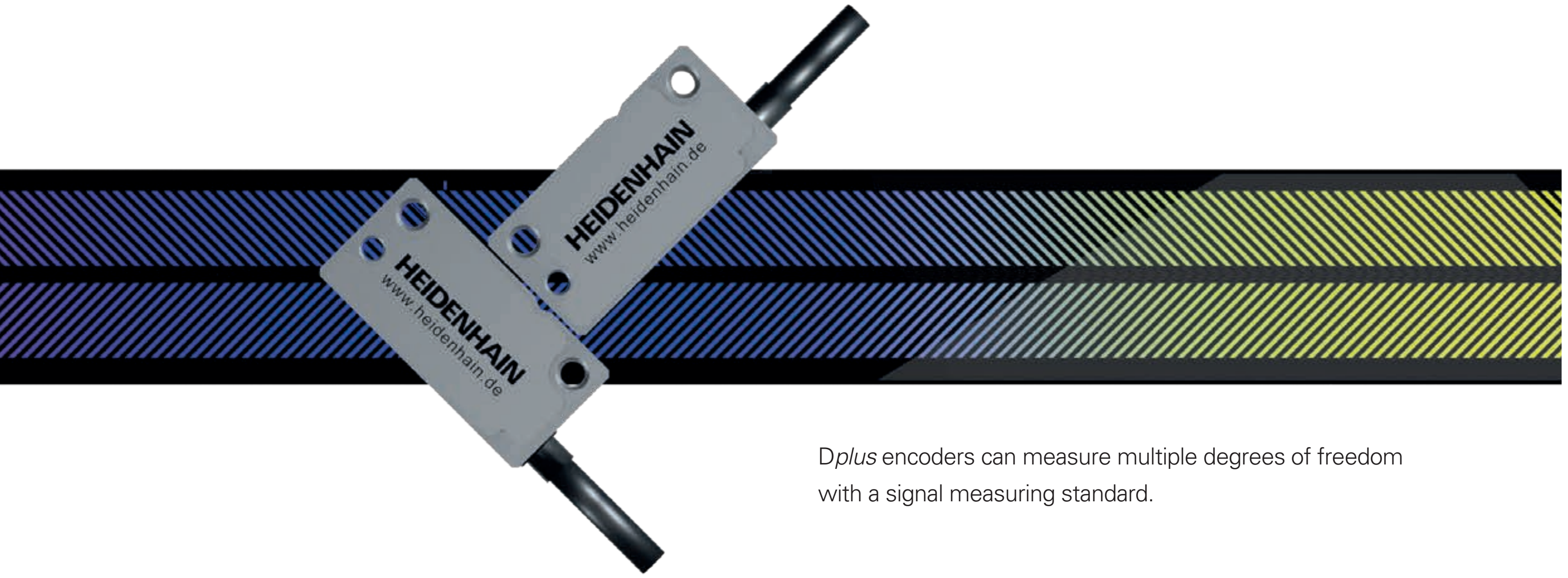
Interferential encoders use signal periods of 4 µm or less, and these largely harmonics-free scanning signals can be highly interpolated. Consequently, these encoders are ideal when high resolution and accuracy are required.

The D*plus* encoders, such as the LIP 6000 D*plus*, have a carrier with two separate graduation tracks featuring diagonal graduations (±45°), thus permitting direct, high-accuracy measurement of the primary and secondary directions along the entire measuring length.

HEIDENHAIN also offers an incremental two-coordinate encoder for equal measurement in two different directions. Neither direction is primary or secondary. In this case, the carrier is itself a high-accuracy grid graduation.

The PP 281 R two-coordinate incremental encoder

One encoder, multiple degrees of freedom



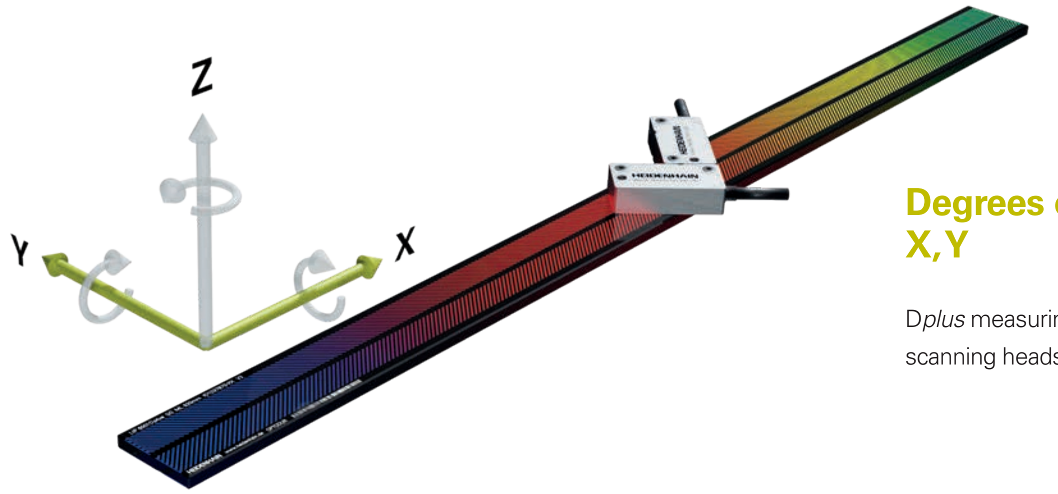
D*plus* encoders can measure multiple degrees of freedom with a signal measuring standard.

Measuring multiple degrees of freedom

A body in space can move along six possible axes. These are divided into translational degrees of freedom (X, Y, Z) and rotational degrees of freedom (R_X, R_Y, R_Z).

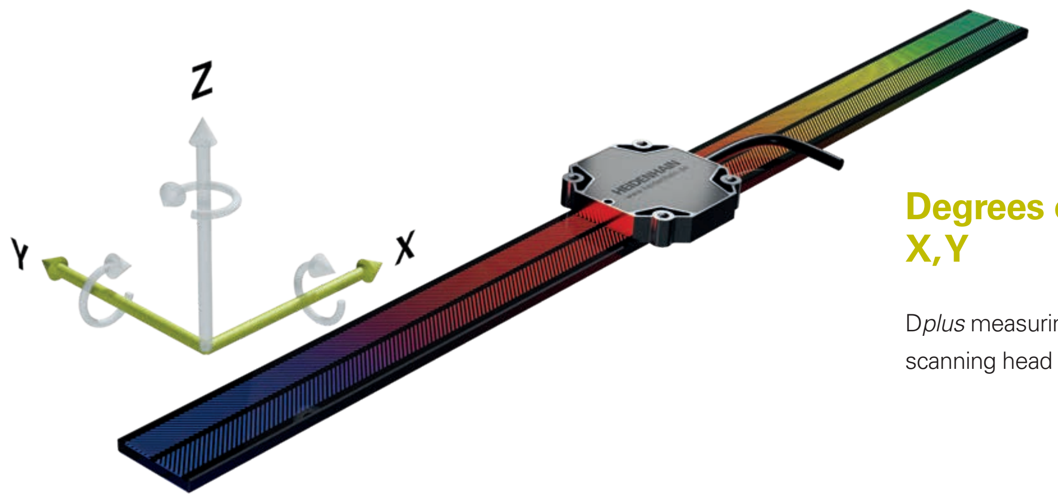
Normally, measuring multiple degrees of freedom requires numerous components. Standard encoders require one scanning head and one measuring standard for each degree of freedom. The D*plus* encoders from HEIDENHAIN, however, can significantly reduce the number of components required.

A D*plus* scale with two separate graduation tracks and three scanning heads on the same scale, for example, can measure up to three degrees of freedom. This technology makes it possible to implement complex measuring tasks in a simple and compact design.



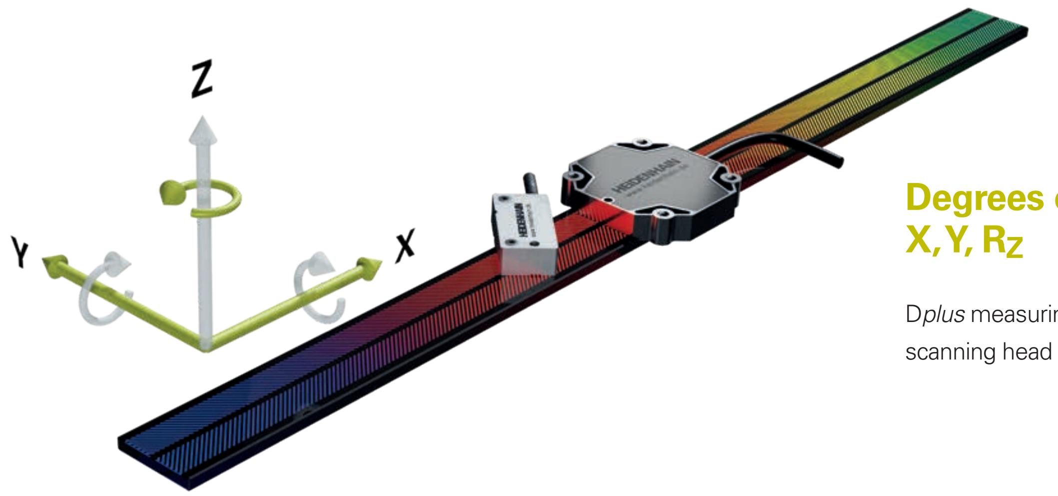
Degrees of freedom: X, Y

D*plus* measuring standard with two scanning heads



Degrees of freedom: X, Y

D*plus* measuring standard with D*plus* scanning head



Degrees of freedom: X, Y, R_Z

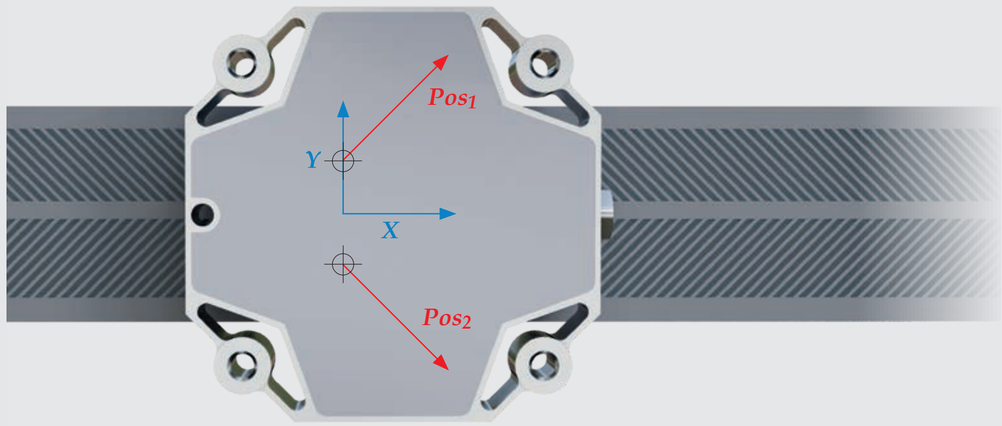
D*plus* measuring standard with standard scanning head and D*plus* scanning head

Diagonal graduations

Position value calculation

$$x = \frac{1}{\sqrt{2}} (Pos_1 + Pos_2)$$

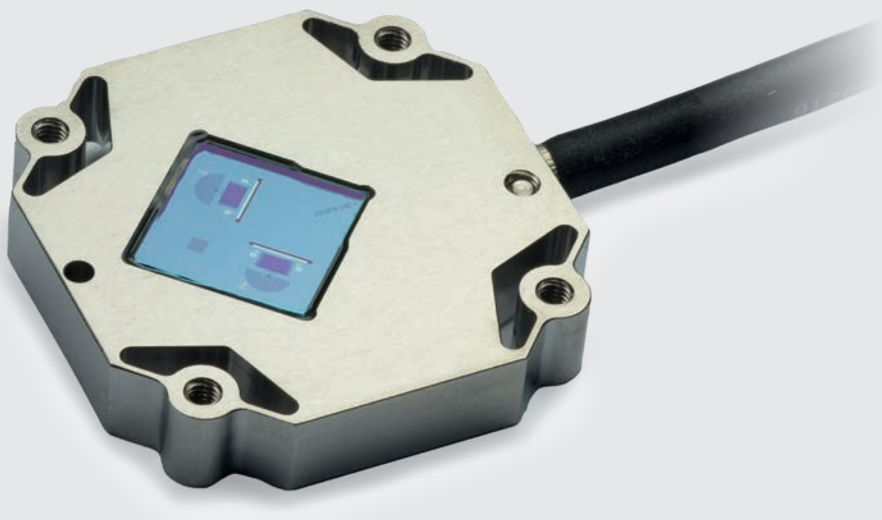
$$y = \frac{1}{\sqrt{2}} (Pos_1 - Pos_2)$$



D*plus*-scanning head

The special D*plus* scanning head developed by HEIDENHAIN can measure two degrees of freedom at the same time. With the EnDat 3 interface, these two position values are forwarded to the control over a single cable.

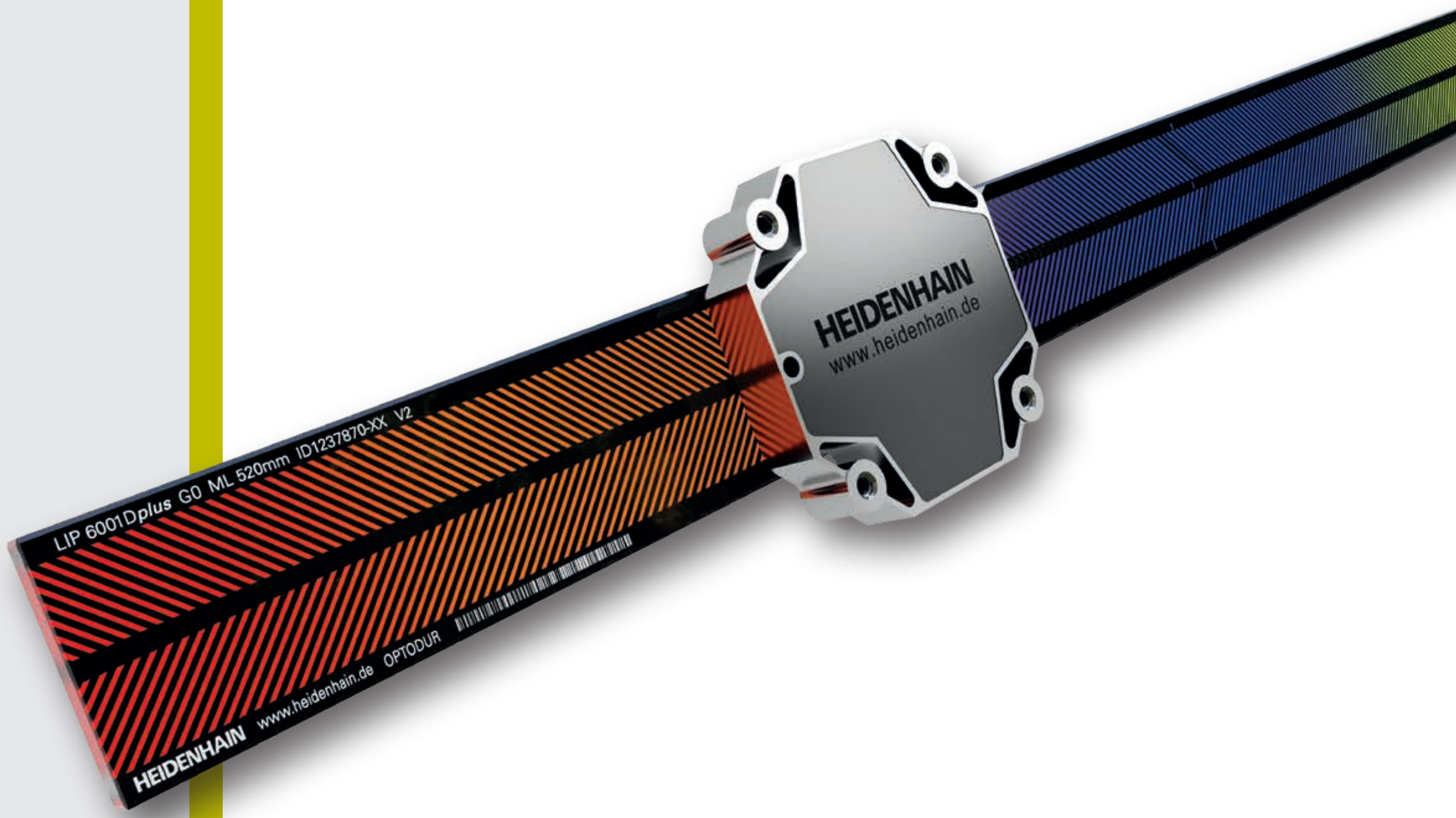
The resulting reduction in cabling not only simplifies installation but also optimizes the dynamic behavior of the motion system.



Harness the advantages of precise error measurement

It would be impossible to home the secondary direction of measurement if the graduations were positioned at right angles (0° and 90°). But with a diagonal configuration, the primary and secondary directions of motion can be homed at the same time.

The resulting absolute position measurement, in turn, lets you achieve greater machine accuracy and identify sources of error.

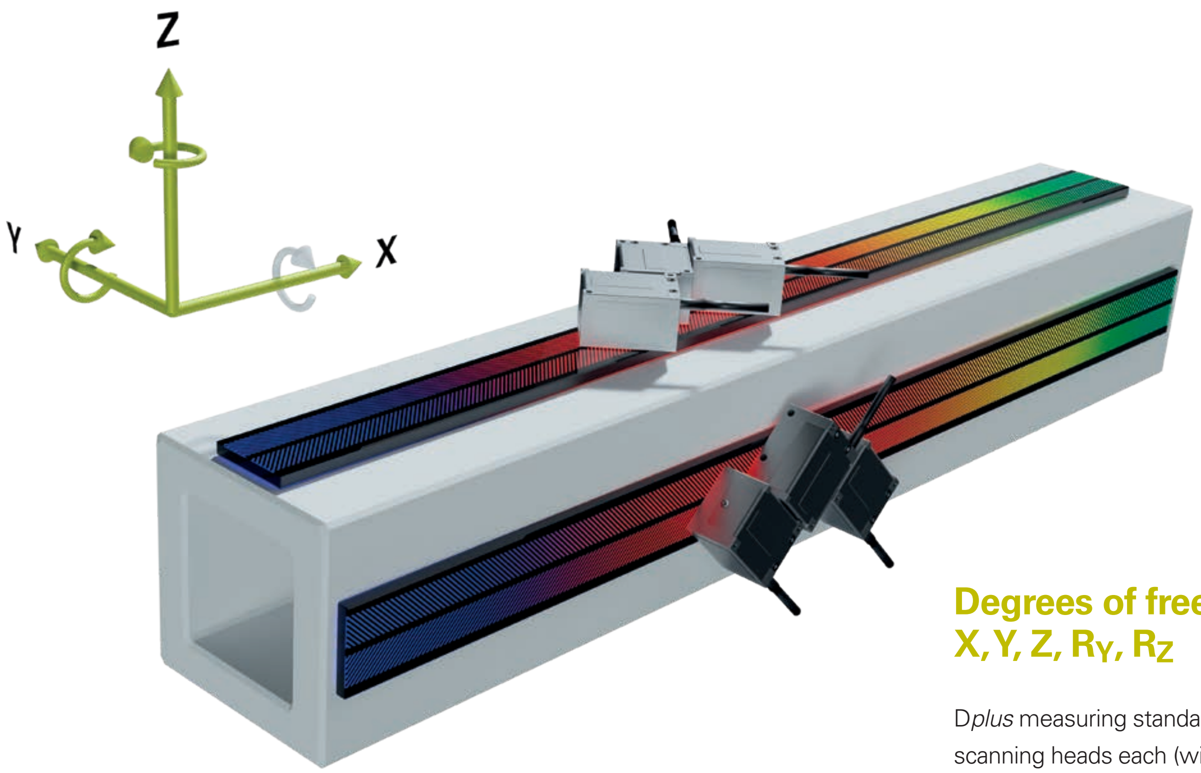


Out-of-plane gap measurement

Conventional encoders can measure only one degree of freedom at a time. D*plus* encoders, however, can measure up to three degrees of freedom in the encoder plane, such as X, Y and R_Z. Additional measurements in a different plane would require additional encoders and a more complex system design.

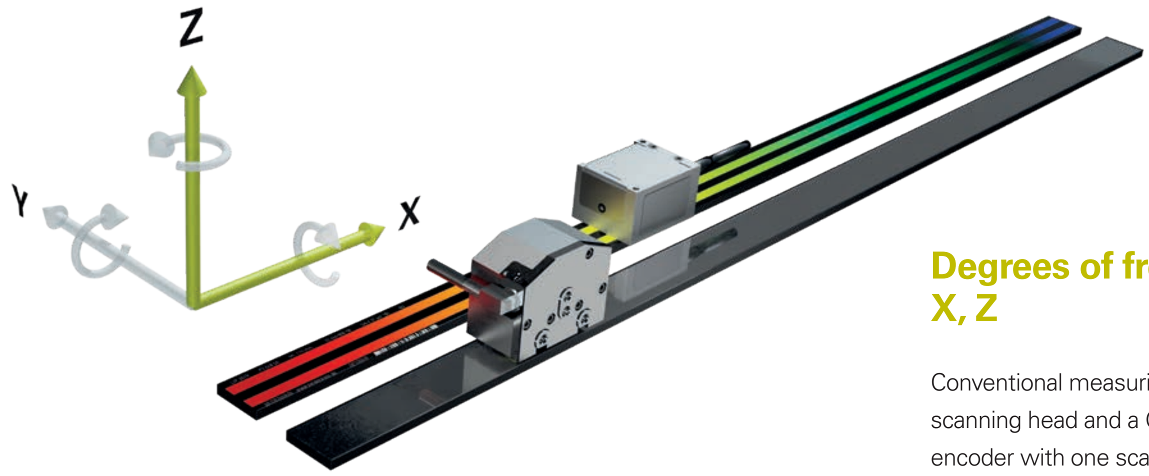
The GAP 1081 gap encoder performs vertical measurement, enabling highly convenient and space-saving system expansion for additional directions. Because its components are mounted in the encoder's main plane, the GAP 1081 delivers rapid measurement directly at the machine.

This encoder can be used for straightforward vertical positioning tasks and continuous vertical measurement along a linear plane. Two scanning heads deployed on a mirror can even measure the pitch or yaw of the given axis, thus greatly simplifying the metrology system design and reducing the required installation work.



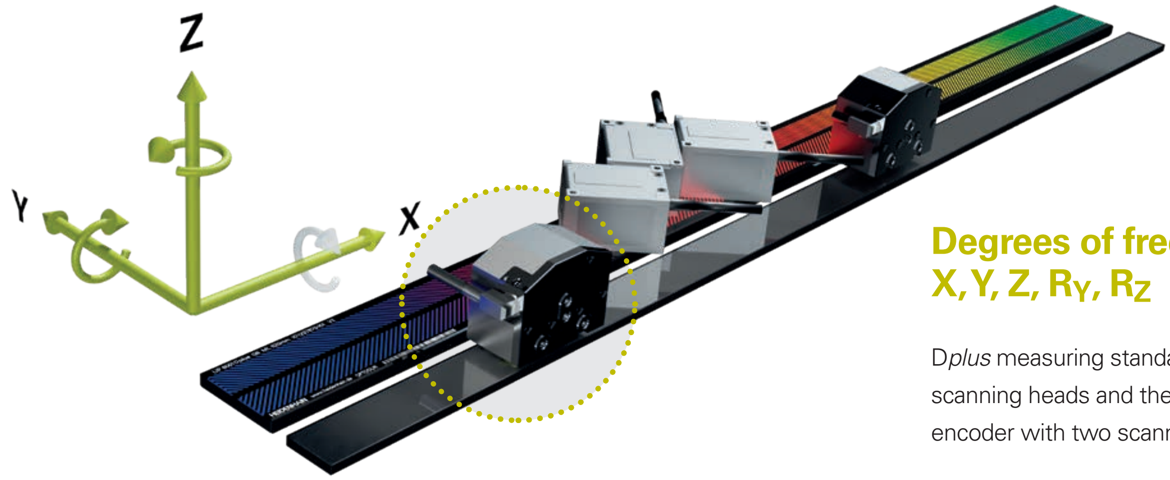
Degrees of freedom:
X, Y, Z, R_Y, R_Z

D*plus* measuring standards with three scanning heads each (without the GAP 1081)



Degrees of freedom:
X, Z

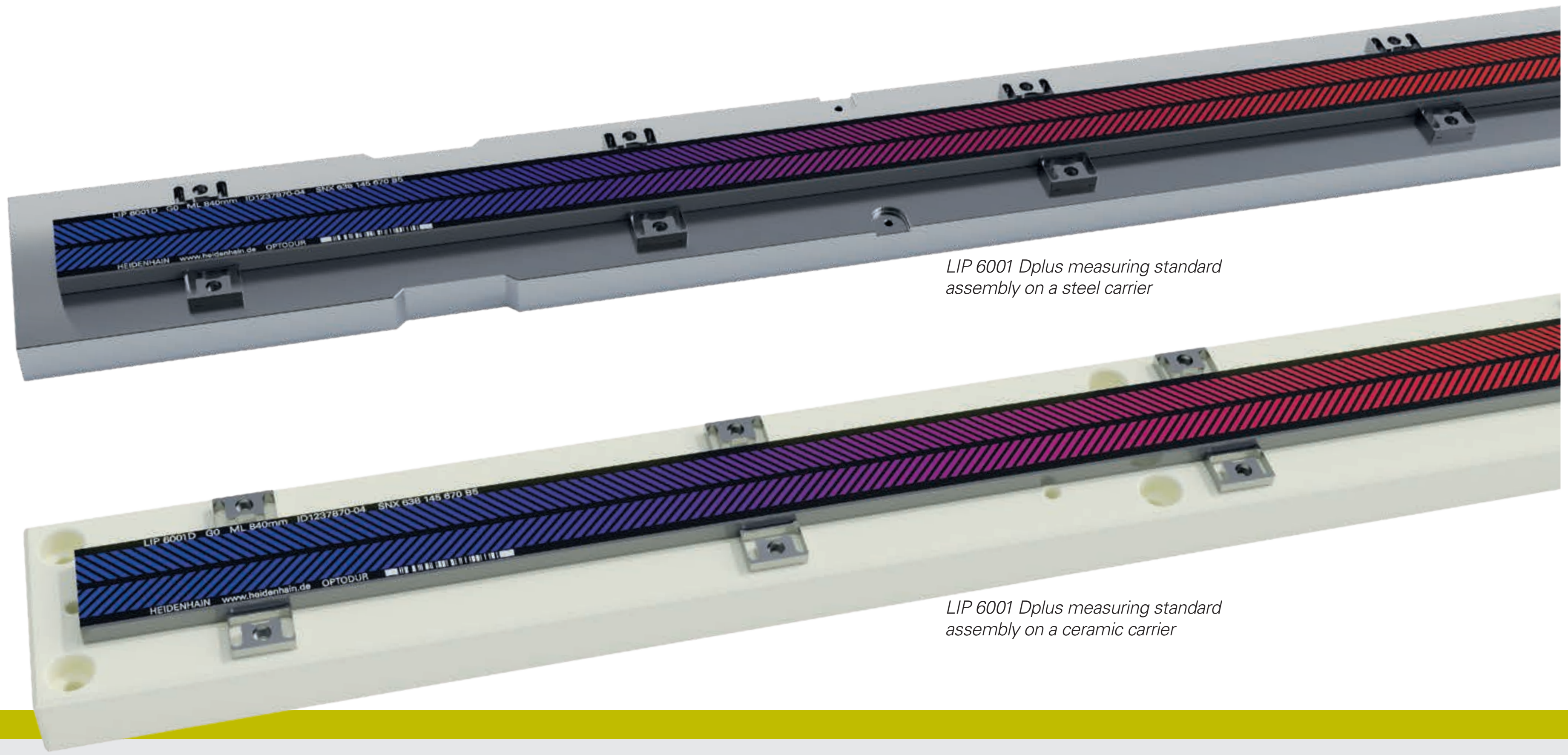
Conventional measuring standard with a scanning head and a GAP 1081 gap encoder with one scanning head



Degrees of freedom:
X, Y, Z, R_Y, R_Z

D*plus* measuring standard with three scanning heads and the GAP 1081 gap encoder with two scanning heads

Transferable accuracy



LIP 6001 Dplus measuring standard assembly on a steel carrier

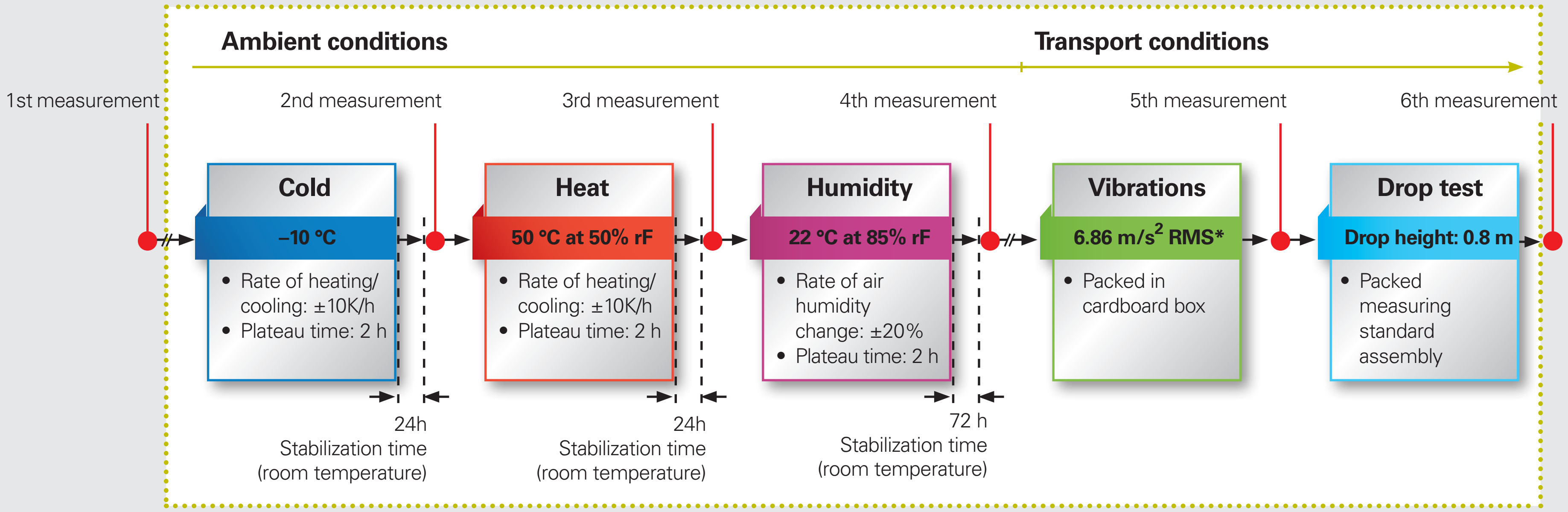
LIP 6001 Dplus measuring standard assembly on a ceramic carrier

Robustness test for the D*plus* measuring-standard assemblies

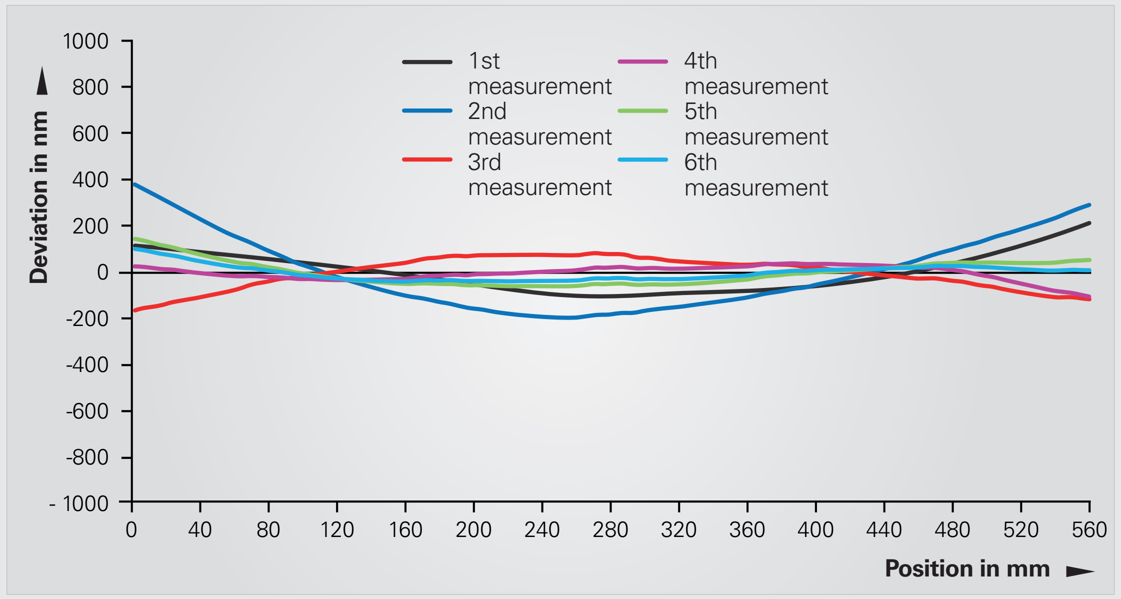
The system accuracy within an application depends not only on how well the encoder was installed but also on the ambient conditions during operation. Thanks to measuring-standard calibrations performed by measuring machines at HEIDENHAIN, the accuracy of the measuring system is increased, and complex on-site, post-installation calibrations are unneeded.

Prior to shipment, the measuring standard is also mounted to a carrier and measured at HEIDENHAIN, thereby decoupling the measuring standard from negative mounting, environmental and transportation factors. As a result, the accuracy measured at HEIDENHAIN is fully transferred from the measuring machine to the application. The calibration table is included.

LIP 6001 D*plus*

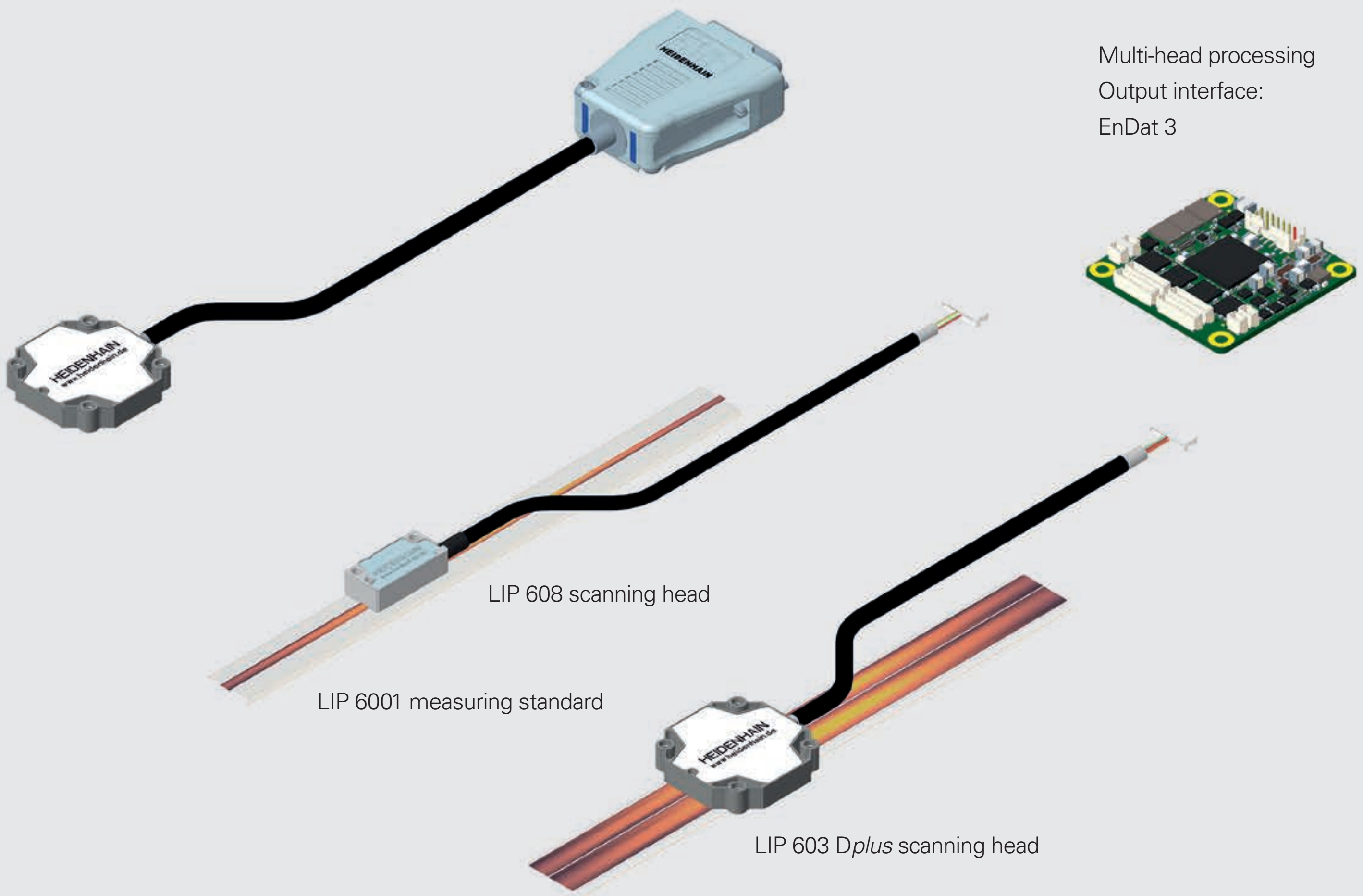


40 min: 3.92 m/s² RMS; 15 min: 5.29 m/s² RMS; 5 min: 6.86 m/s² RMS (ASTM D 4169)



Straightness deviation relative to the measuring length

Less cabling and higher dynamic performance

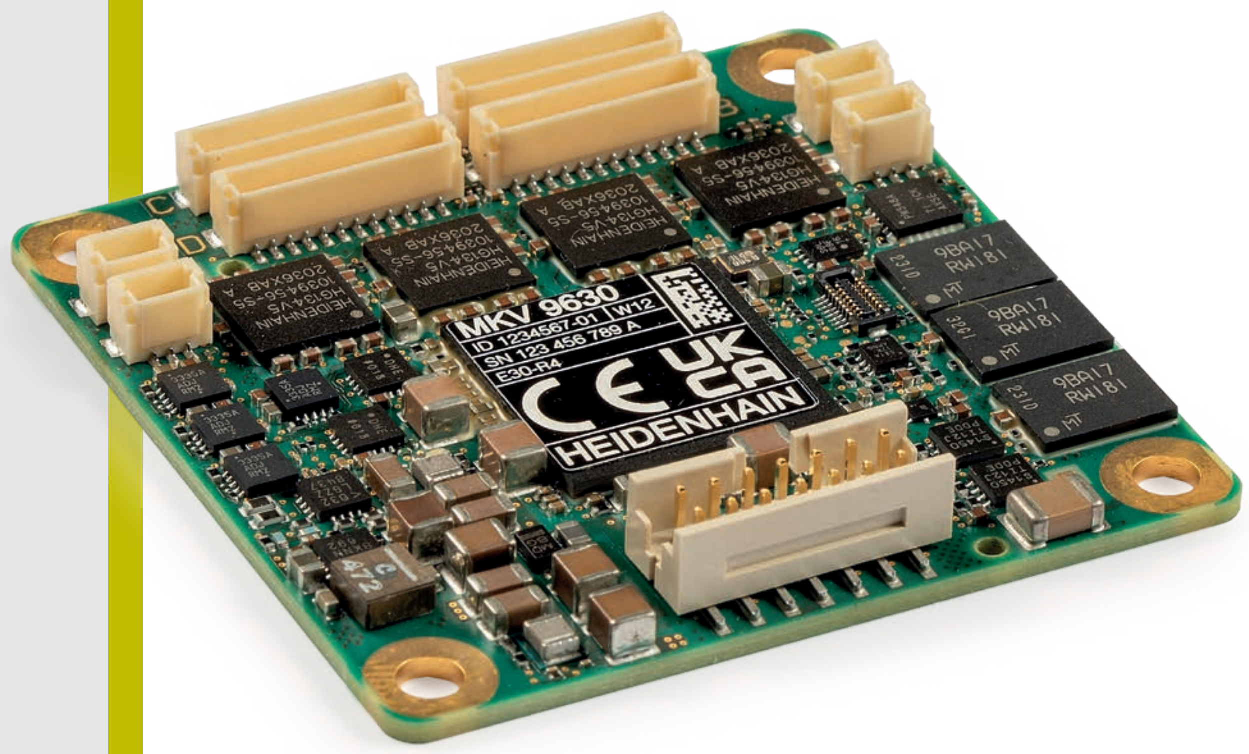


Multi-head processing with EnDat 3

The use of multiple encoders increases overall system cabling, making installation and downstream processing more complex. With the EnDat 3 interface, HEIDENHAIN offers the optimal solution for transmitting a wide range of data on just one cable. Two position values, for example, are calculated in the interface PCB of a D*plus* encoder and transmitted over a single cable.

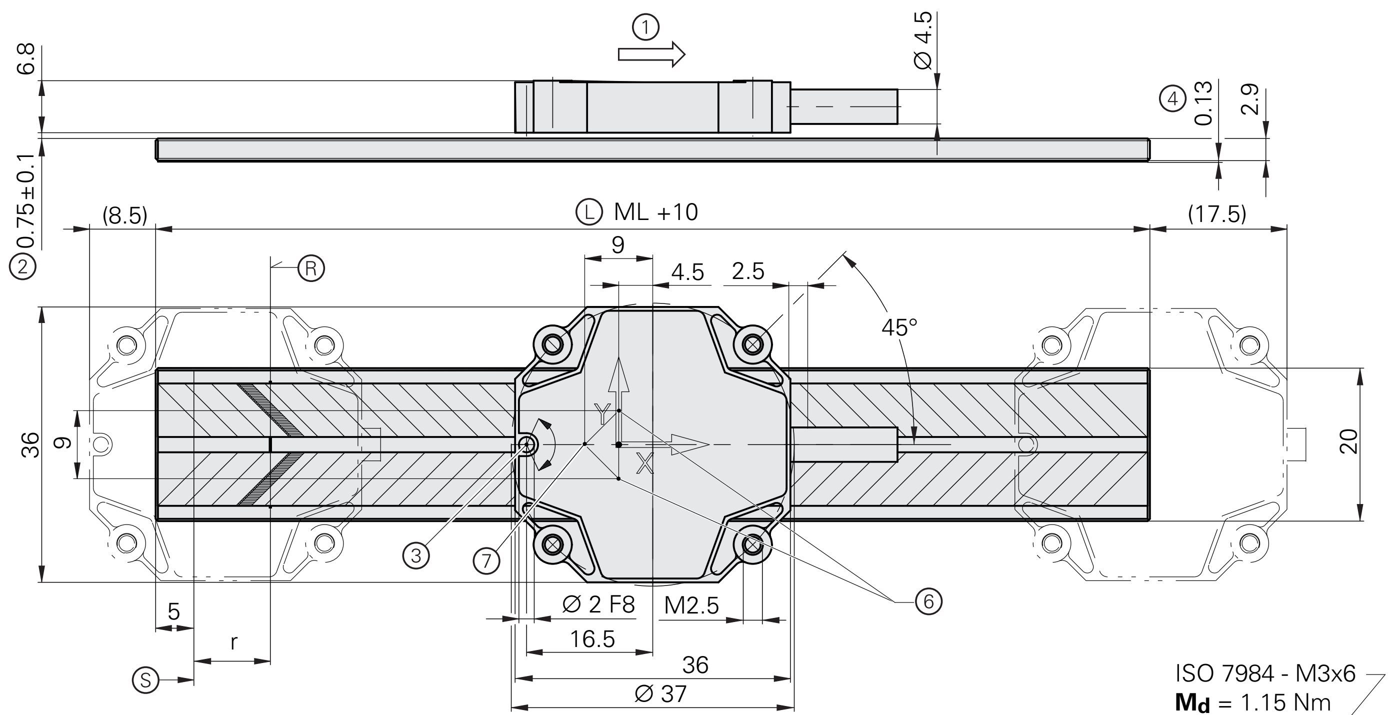
For single-cable transmission, the multi-head processing electronics process the position signals of multiple encoders.

This permits convenient implementation of complex metrology system designs without extensive cabling or separate position value processing.

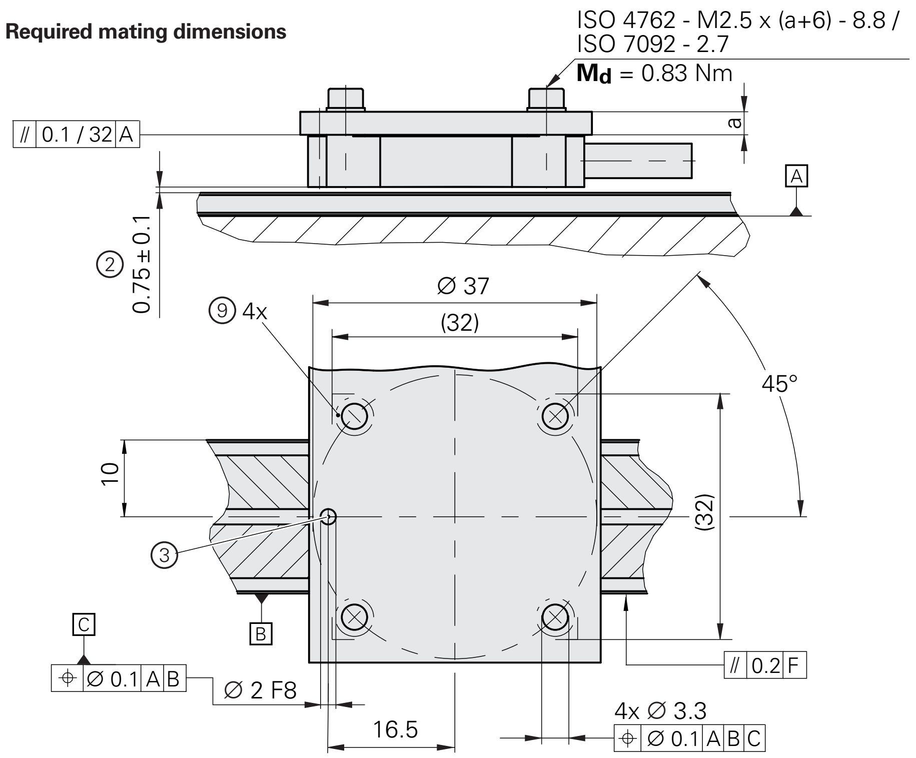


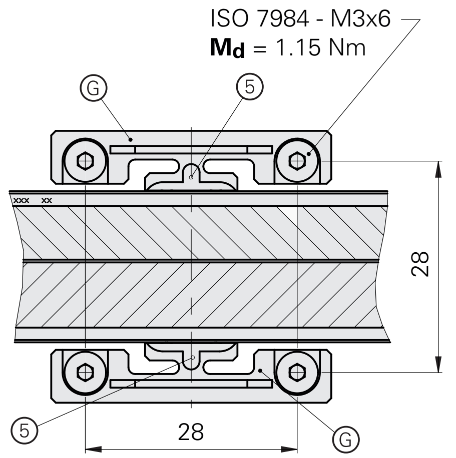
LIP 6031 D*plus*

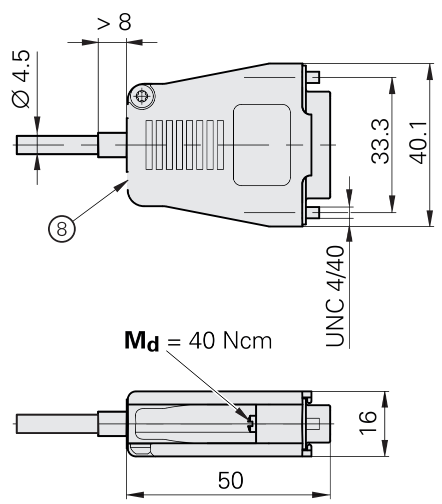
Incremental exposed linear encoder
- Two diagonal graduations ±45° for measuring the primary and secondary directions
- Glass scale made of glass ceramic; mounting with PRECIMET and fixed-point elements



Required mating dimensions







F = Machine guideway
Ⓛ = Scale length
Ⓡ = Reference mark position
Ⓢ = Beginning of measuring length (ML)
Ⓖ = Fixed point for defining the thermal fixed point
r = Reference mark position from the beginning of the measuring length (ML)
1 = Direction of motion of the scanning unit for increasing position values
2 = Adjustment of the scanning gap
3 = Moiré adjustment: alignment pin: Ø 2m6
4 = Adhesive tape
5 = Adhesive
6 = Center of 1 and 2 of the scanning head
7 = Neutral center of rotation of the scanning head
8 = Signal quality indicator
9 = Bearing surface of encoder

mm
Tolerancing ISO 8015
ISO 2768:1989-mH
≤ 6 mm: ±0.2 mm

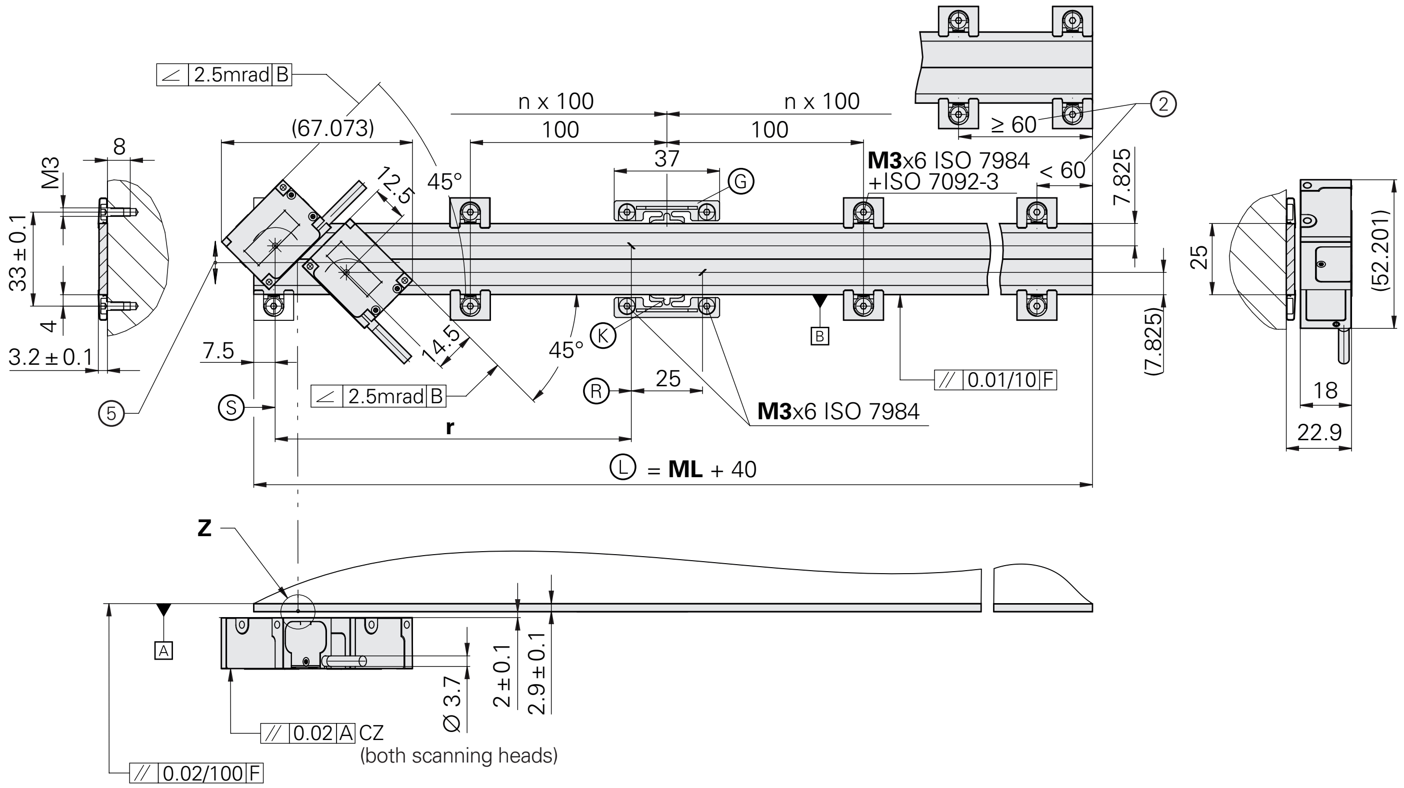
Scale	LIP 6001 D*plus*
Measuring standard Coefficient of linear expansion	OPTODUR phase grating on Zerodur glass ceramic; graduation period: 8 µm $\alpha_{therm} \approx (0 \pm 0.1) \cdot 10^{-6}\ K^{-1}$
Accuracy grade	X direction: ±3 µm; Y direction: ±20 µm
Baseline error	X direction: ±0.175 µm/5 mm; Y direction: ±0.350 µm/5 mm
Measuring length (ML) in X direction in mm*	70 120 170 220 270 320 370 420 470 520 570 620 670 720 770 820 870 920 970 1020 1140 1240 1340 1440 1540 1640 1840 2040 2240 2440 2640 2840 3040
Measuring length in Y direction	±2 mm
Reference mark	One at the beginning of the measuring length
Mass	0.15 g/mm

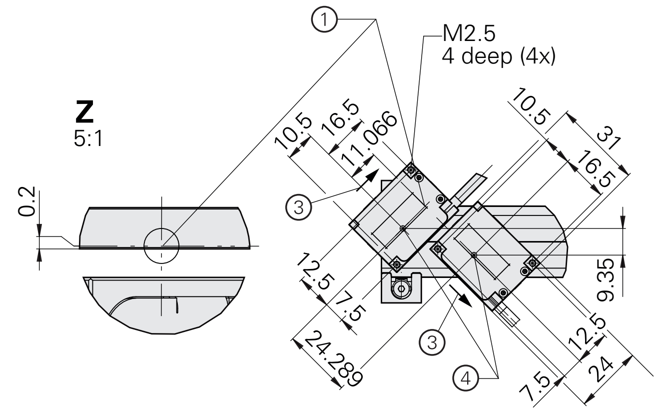
Scanning head	LIP 603 D*plus*
Interface	EnDat 3
Ordering designation	E30-R4
Measuring step	172 pm
Availability of position value	X direction: < 11 µs at 12.5 Mbit/s; < 8.2 µs at 25 Mbit/s[1] Y direction: < 18.7 µs at 12.5 Mbit/s; < 12.1 µs at 25 Mbit/s[2]
Traversing speed	≤ 240 m/min[3]
Interpolation error	±5 nm
RMS position noise	0.5 nm (1 MHz)
Electrical connection	Cable (0.5 m/1 m/3 m) with interface electronics in the connector (15-pin D-sub (male))
Cable length	12.5 Mbit/s: ≤ 100 m; 25 Mbit/s: ≤ 40 m During signal adjustment with the PWM 21: ≤ 3 m
Supply voltage	DC 3.6 V to 14 V (recommended: 12 V)
Power consumption[4] (max.)	3.6 V: ≤ 1.5 W; 14 V: ≤ 1.8 W
Current consumption	At 12 V: 110 mA (without load, typical)
Vibration 55 Hz to 2 kHz **Shock** 11 ms	≤ 500 m/s² (EN 60068-2-6) ≤ 1000 m/s² (EN 60068-2-27)
Operating temperature	–10 °C to 70 °C
Mass Scanning head APE connector Connecting cable	≈ 30 g ≈ 77 g ≈ 36 g/m

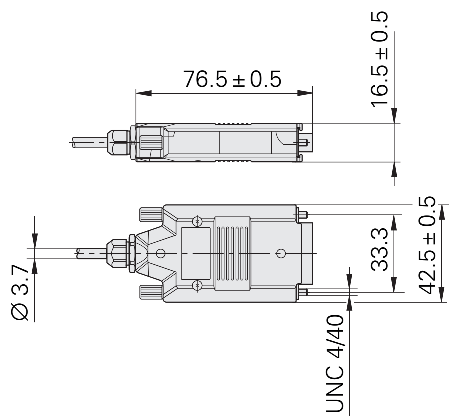
* Please select when ordering
[1] This value is stored in the encoder as the parameter XEL.timeHPFout and outputs the time interval between the position-value request (latch) and the availability of the position value in the Master (without cable factors)
[2] With transmission in the first LPF
[3] Maximum traversing speed when the reference mark is cross (120 m/min)
[4] See *General electrical information* in the *Interfaces of HEIDENHAIN Encoders* brochure or under *www.heidenhain.com.*

LIP 211D*plus*/LIP 281D*plus*/LIP 291D*plus*

Incremental exposed linear encoder
- Two diagonal graduations ±45° for measuring the primary and secondary directions
- Measuring scale made of glass ceramic; mounting with PRECIMET and fixed-point elements

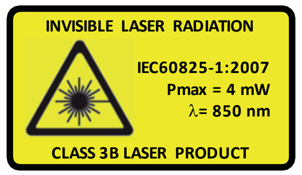






F = Machine guideway
Ⓛ = Scale length
Ⓡ = Reference mark position
Ⓢ = Beginning of measuring length (ML)
Ⓚ = Adhesive
Ⓖ = Mounting element for adhesive bond for defining the thermal fixed point
1 = Neutral center of rotation (0.2 mm under the scale surface)
2 = Depends on the measuring length (ML), additional fix clamp pair
3 = Direction of motion of the scanning unit for ascending position values
4 = Optical centerline
5 = Transversal ML: ±0.6 mm

mm
Tolerancing ISO 8015
ISO 2768:1989-mH
≤ 6 mm: ±0.2 mm



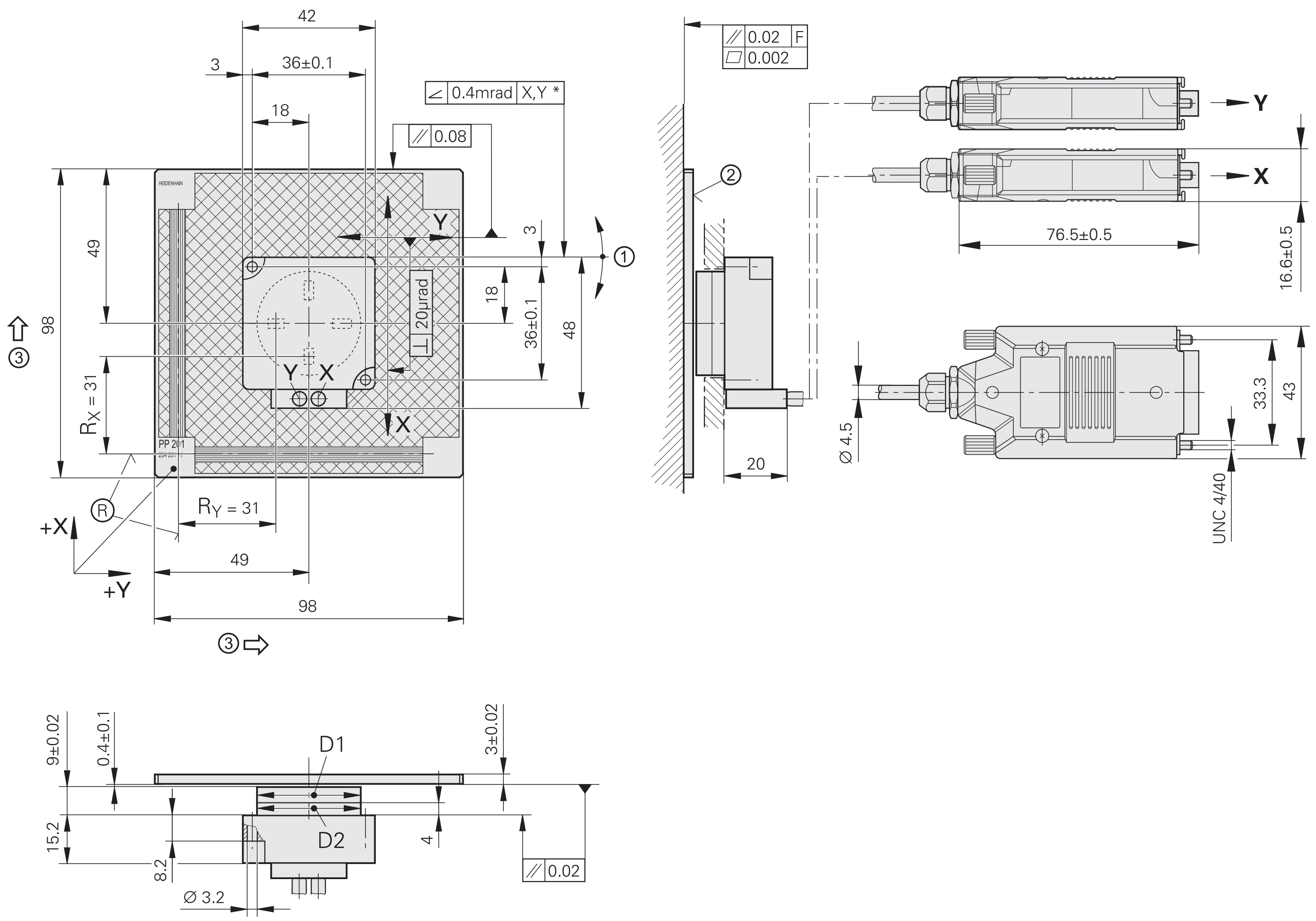
Scale	**LIP 201 D*plus***
Measuring standard Coefficient of linear expansion	OPTODUR phase grating on Zerodur glass ceramic; graduation period: 2.048 µm $\alpha_{therm} \approx (0 \pm 0.1) \cdot 10^{-6}\ K^{-1}$
Accuracy grade	X direction: ±3 µm; Y direction: ±20 µm
Baseline error	X direction: ±0.125 µm/5 mm; Y direction: ±0.225 µm/5 mm
Measuring length in the X direction (ML) in mm*	70 120 170 220 270 320 370 420 470 520 570 620 670 720
Measuring length in Y direction	±2 mm[1]
Reference mark	One at midpoint of measuring length
Mass	7.2 g + 0.18 g/mm

Scanning head	**LIP 21**	**LIP 29F**	**LIP 29M**	**LIP 28**
Interface	EnDat 2.2[2]	Fanuc Serial Interface[2]	Mitsubishi high speed[2]	∿ 1 V_{PP}
Ordering designation	EnDat22	Fanuc02	Mit02-4	–
Integrated interpolation	16384-fold (14 bit)			–
Clock frequency	≤ 16 MHz	–		–
Calculation time t_{cal}	≤ 5 µs	–		–
Measuring step	0.03125 nm (31.25 pm)			–
Signal period	–			0.512 µm
Cutoff frequency –3 dB	–			≥ 3 MHz
Traversing speed	≤ 120 m/min			≤ 90 m/min
Interpolation error	±0.4 nm[3]			
RMS position noise	0.12 nm			0.12 nm (3 MHz[4])
Electrical connection	Cable (0.5 m) or 1 m (2 m and 3 m at 1 V_{PP}) with interface electronics in the connector (15-pin D-sub (male))			
Cable length	See *Interface description*; however ≤ 15 m (≤ 30 m at 1 V_{PP}) with HEIDENHAIN cable During signal adjustment with the PWM 21: ≤ 3 m			
Supply voltage	DC 3.6 V to 14 V			DC 5 V ±0.25 V
Power consumption[5] (max.)	*At 14 V:* 2500 mW; *at 3.6 V:* 2600 mW			–
Current consumption	*At 5 V:* 300 mA (without load, typical)			≤ 390 mA
Laser	*Mounted scanning head and scale:* Class 1; *non-mounted scanning head:* Class 3B			
Vibration 55 Hz to 2000 Hz **Shock** 11 ms	≤ 200 m/s^2 (IEC 60068-2-6) ≤ 400 m/s^2 (IEC 60068-2-27)			
Operating temperature	0 °C to 50 °C			
Mass	*Scanning head:* 59 g; *connector:* 140 g; *connecting cable:* 22 g/m			

* Please select when ordering; [1] Measuring length in Y direction upon traversing of the reference mark: ±0.6 mm; [2] Absolute position value after traversing of the reference mark in "position value 2"; [3] With HEIDENHAIN signal converter; [4] –3 dB cutoff frequency of the downstream electronics; [5] See *General electrical information* in the *Interfaces of HEIDENHAIN Encoders* brochure.

PP 281 R

Two-coordinate incremental encoder
- For measuring steps of 1 µm to 0.05 µm

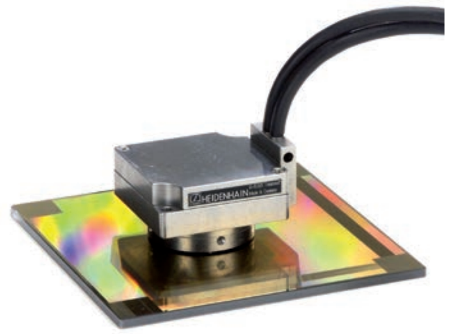


mm

Tolerancing ISO 8015
ISO 2768:1989-mH
≤ 6 mm: ±0.2 mm

* = Maximum change during operation
F = Machine guideway
Ⓡ = Reference-mark position relative to center position shown
1 = Adjusted during mounting
2 = Graduation side
3 = Direction of motion of the scanning unit for increasing position values

D1	D2
Ø 32.9 –0.2	Ø 33 –0.02/–0.10

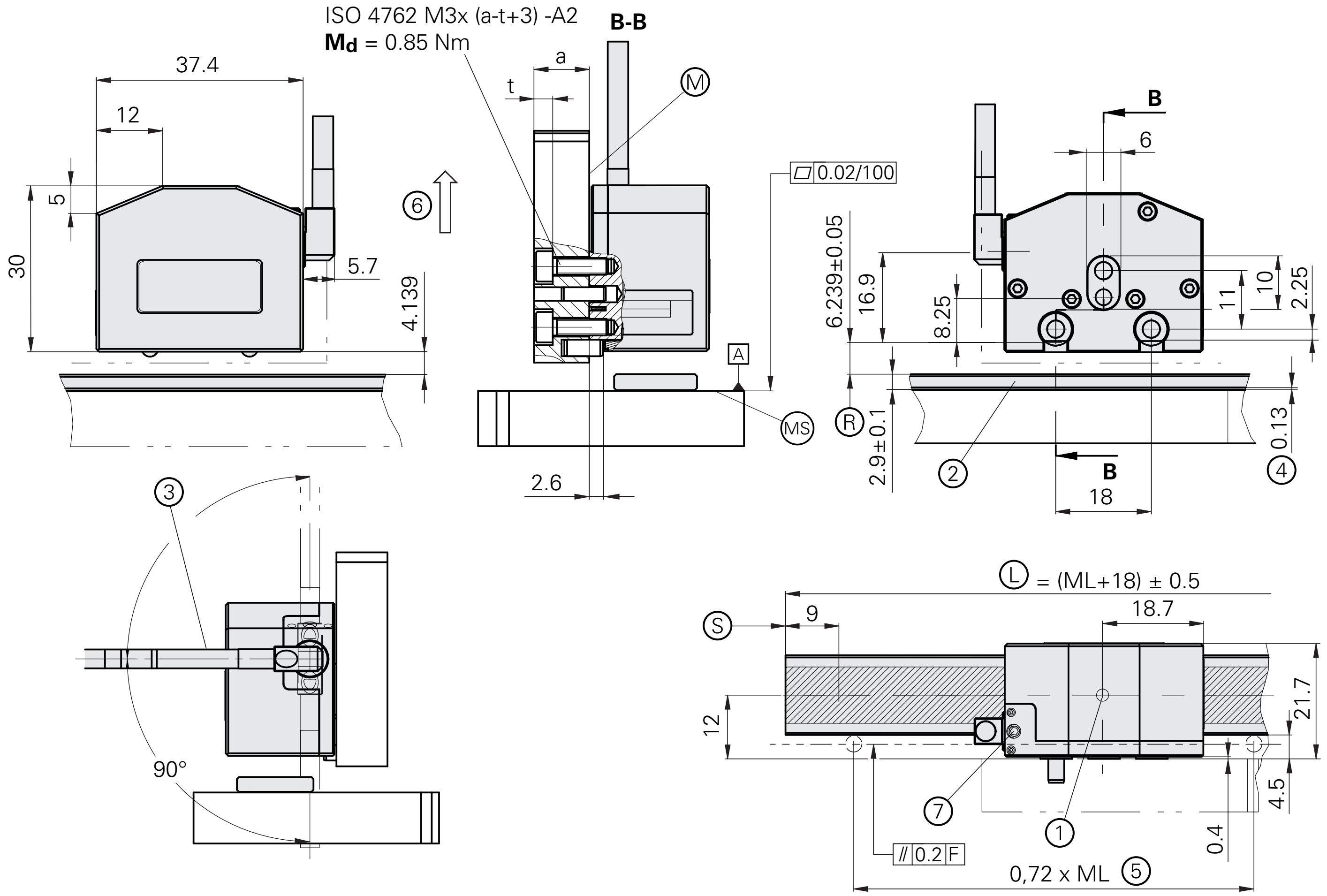


	PP 281 R
Measuring standard Coefficient of linear expansion	Two-coordinate TITANID phase grating on glass; grating period: 8 µm $\alpha_{therm} \approx 8 \cdot 10^{-6}\ K^{-1}$
Accuracy grade	±2 µm
Measuring area	68 mm x 68 mm, other measuring areas upon request
Reference marks[1]	One reference mark in each axis, 3 mm after beginning of measuring length
Interface	∿ 1 V_{PP}
Signal period	4 µm
Cutoff frequency –3 dB	≥ 300 kHz
Traversing speed	≤ 72 m/min
Interpolation error **RMS position noise**	±12 nm[3] 2 nm (450 kHz[2])
Electrical connection	Cable (0.5 m) with 15-pin D-sub connector (male); interface electronics in the connector
Cable length	See the interface description (in accordance with the interface electronics); however, ≤ 30 m (with HEIDENHAIN cable)
Supply voltage	DC 5 V ±0.25 V
Current consumption	< 185 mA per axis
Vibration 55 Hz to 2000 Hz **Shock** 11 ms	≤ 80 m/s^2 (EN 60068-2-6) ≤ 100 m/s^2 (EN 60068-2-27)
Operating temperature	0 °C to 50 °C
Mass Scanning head Grid plate Connector	170 g (without cable) 75 g 140 g

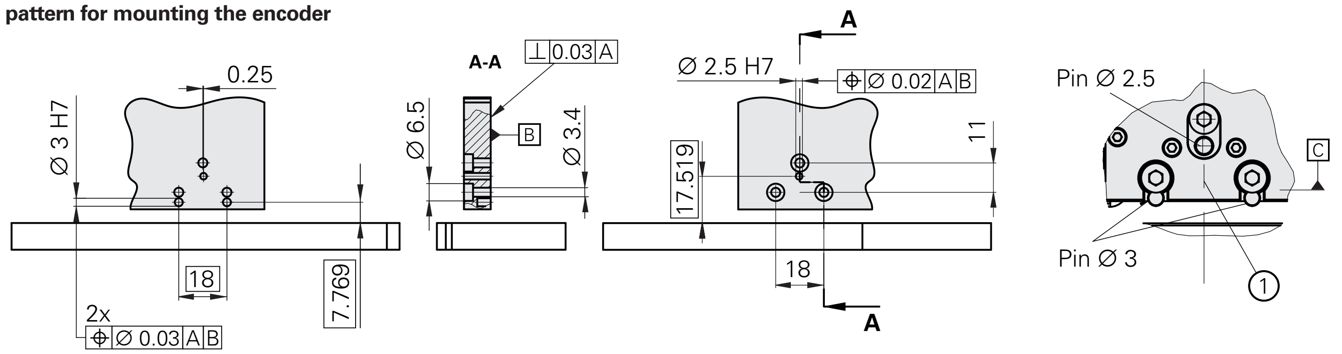
[1] The reference mark signal deviates from the interface specification in its zero crossovers K, L (see the mounting instructions)
[2] –3 dB cutoff frequency of the downstream electronics
[3] With HEIDENHAIN signal converter (e.g., EIB 741)

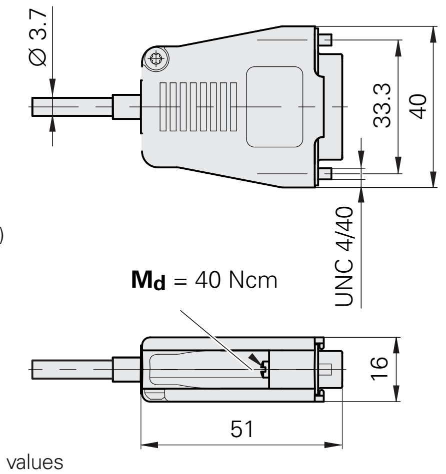
GAP 1081

Incremental exposed linear encoder
- For vertical gap measurement
- Mirror on glass; mounting with PRECIMET



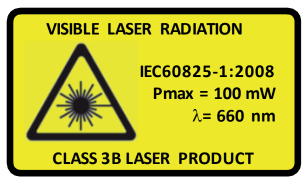
Hole pattern for mounting the encoder





Ⓛ = Scale length
Ⓜ = Mounting surface for the encoder
MS = Mounting surface for the scale
Ⓢ = Beginning of z measurement (with simultaneous x movement)
Ⓡ = Reference mark position
ML = Measuring length
F = Machine guideway
1 = Optical center
2 = Scale
3 = Cable length
4 = Adhesive tape
5 = Position of stop pins; recommendation Ø 3
6 = Direction of motion of the scanning unit for increasing position values
7 = Clamping screw (width A/F: 1.3 mm); Md = 30 ±1.8 Nm

mm
Tolerancing ISO 8015
ISO 2768:1989-mH
≤ 6 mm: ±0.2 mm



Mirror	GAP 1001
Mirror Coefficient of linear expansion	Glass or glass ceramic with Optodur surface layer $\alpha_{therm} \approx (0\pm0{,}1) \cdot 10^{-6}\ K^{-1}$ (Zerodur glass ceramic); $\alpha_{therm} \approx 8 \cdot 10^{-6}\ K^{-1}$ (glass)
Measuring length (ML) in mm*	20 30 50 70 120 170 220 270 320 370 420 470 520 570 620 670 720 780 820 870 920 970 1020 1140 1240 1340 1440 1540 1640 1840 2040 2240 2440 2640 2840 3040
Mass	1.1 g + 0.11 g/mm of mirror length

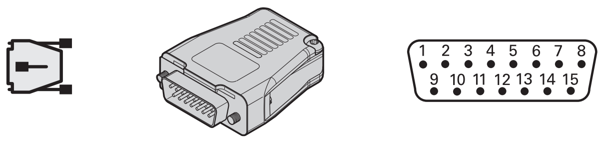
Scanning head	GAP 108
Scanning gap (nominal)	4.139 mm
Measuring range	±2 mm
Reference mark	One at midpoint of measuring length
Interface	1 V_{PP}
Cutoff frequency –3 dB	≥ 27 kHz
Signal period Coefficient of linear expansion	2.220 ±0.002 µm $\alpha_{therm} \approx 0.5 \cdot 10^{-6}\ K^{-1}$
Traversing speed	3.6 m/min
Accuracy grade	±0.2 µm (measurement from a fixed location in the direction of measurement) ±20 µm (motion perpendicular to the direction of measurement)
Baseline error	≤ ±30/4 mm (measurement from a fixed location in the direction of measurement) ≤ ±0,5 µm/5 mm (with motion perpendicular to the direction of measurement)
Thermal position drift	≤ ±36 nm/K
Interpolation error	±2 nm
Non-reproducible position error	±5 nm
Electrical connection	Cable (0.5 m/1 m/3 m) with 15-pin D-sub connector; interface electronics in the connector
Cable length	*With HEIDENHAIN cable:* ≤ 30 m *During signal adjustment with the PWM 21:* ≤ 3 m
Supply voltage	DC 5 V ±0.25 V
Current consumption	≤ 200 mA (without load)
Laser	Class 3B
Vibration 55 Hz to 2 kHz **Shock** 11 ms	≤ 200 m/s^2 (IEC 60068-2-6) ≤ 400 m/s^2 (IEC 60068-2-27)
Operating temperature	22 °C ±5 °C[1]
Mass Scanning head Connector Cable	≈ 50 g ≈ 80 g ≈ 27 g/m

* Please select when ordering
[1] During referencing: temperature during adjustment ±2.5 °C during single-side approach

Pin layout

LIP 603

15-pin D-sub connector



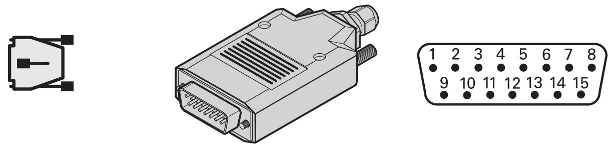
	Power supply				Other signals									Serial data transfer	
	4	**12**	**2**	**10**	**1**	**9**	**3**	**11**	**14**	**7**	**13**	**5**	**6**	**8**	**15**
	UP	**Sensor** UP	**0 V**	**Sensor** 0 V	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**Vacant**	**SD+**	**SD–**
[1]	Brown/Green	/	White/Green	/	/	/	/	/	/	/	/	/	/	Violet	Yellow

Cable shield on housing; **UP** = Power supply voltage
Sensor: The sense line is connected in the encoder with the corresponding power line.
Vacant pins or wires must not be used.

[1] Color assignment of the connecting cable

LIP 281 and PP 281 R

15-pin D-sub connector



	Power supply				Incremental signals						Other signals			
	4	**12**	**2**	**10**	**1**	**9**	**3**	**11**	**14**	**7**	**13**	**5**	**6/8**	**15**
∼ **1 VPP**	**UP**	**Sensor** 5 V	**0 V**	**Sensor** 0 V	**A+**	**A–**	**B+**	**B–**	**R+**	**R–**	**As-signed**[1] **Vacant**[3]	**As-signed**[1] **Vacant**[3]	**/**	**As-signed**[1] **Vacant**[3]
[2]	Brown/Green	Blue	White/Green	White	Brown	Green	Gray	Pink	Red	Black	Violet	Red/Black	/	Yellow

Cable shield on housing; **UP** = Power supply voltage
Sensor: The sense line is connected in the encoder with the corresponding power line.
Vacant pins or wires must not be used.

[1] Only for adjusting, do not use in normal operation
[2] Color assignment of the connecting cable
[3] PP 281 R

Further information:

For detailed descriptions of cables, please refer to the *Cables and Connectors* brochure.

HEIDENHAIN

Mastering nanometer accuracy

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