HEIDENHAIN FO
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Linear Encoders for Production-Integrated Measuring Machines

The Coefficient of Expansion Determines the Accuracy

Up to now, measuring machines have operated in a largely familiar, exactly defined environment, since their performance is significantly determined by the signal quality and accuracy of their linear encoders. Now, with the trend toward production-integrated measuring machines, the measurement device in use should be clearly reviewed.

Trend toward production-integrated measurement
A measuring room offers optimum conditions for precise measurements. Its disadvantages include high costs for the room, the machine and temperature stabilization, and most notably, the interruption in the flow of production. Following the general trend of increasing control of the manufacturing flow in series production, the measuring machine is coming spatially closer to actual production. This is known as production-integrated measurement. It enables the results of measurement to go "online" into the control of production and thereby enhance the precision of the manufacturing process. High cost-effectiveness and time savings are factors driving this trend.

Expansion of previously known requirements
The harsh nature of a typical manufacturing environment has placed on measuring machines new requirements that either did not exist or were less critical in the sheltered surroundings of a measuring room. Measuring machines on the shop floor are exposed to changing temperatures and more difficult ambient conditions. Shock, vibrations and contamination are nothing unusual there.

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Manufacturers of measuring machines are responding to these requirements with various designs and solutions. However, all are in agreement on one point: Deviations from the 20 °C reference temperature specified in DIN 102 result in changes of length and angle on both the workpiece and the measuring machine, and these changes have to be mathematically compensated.

A defined, reproducible thermal behavior of the encoder is indispensible for such deviations. The encoder therefore becomes particularly important. The **encoder's coefficient of expansion** and its tolerances will play a more significant role in future ISO standards for classifying coordinate measuring machines (see ISO TC 213-WG 10).

Thermal expansion = change of length—an unknown quantity?

continued on next page

Did You Know...

DID YOU KNOW…

…that a HEIDENHAIN angle encoder is a vital component in Adcole's Model 1200 measuring machine known worldwide as the standard for measuring engine crankshafts and camshafts? Adcole Corporation (www.adcole.com) headquartered in Massachusetts, takes great pride as the market leader and asserts its ability to provide the highest accuracy cylindrical coordinate measuring machines (CMMs). "No other company can better measure critically important reciprocating engine components," said Steve Corrado, Adcole's Engineering Manager.

Adcole is celebrating its 52nd year in business. "We go way back with HEIDENHAIN," said founding father Addison Cole. "In the late 60s, I had a relationship with the late Dr. Heidenhain himself, including visiting the company plants in Traunreut, Germany. He was an impressive man, and we held similar interests including a profound belief in the ability to provide highly accurate measurement systems. We have now been using HEIDENHAIN reticles and encoders for approximately three decades."

Currently Adcole is using HEIDENHAIN's ERA 4280 angle encoder in its ultra-precise rotary table headstock, a key component of its laser interferometer-based Model 1200. Combining sub-arc second rotary measurements with nanometer-level linear measurements allows Adcole's customers to measure

Adcole Model 1200 measuring machine.

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Did you know *continued from Page 1*

roundness, diameter and other critical parameters on crankshafts and camshafts to accuracies of less then 0.25 microns. "The ERA 4280 has an angle accuracy of ±2.5 arc seconds, which is about 2 to 3 times better than our previous design, and makes it easier for us to calibrate the encoder to a fraction of an arc second," said Corrado. "It was significantly less expensive to purchase the encoder and read heads as an assembly from HEIDENHAIN than do it ourselves. Plus the ERA 4280 encoder is steel instead of glass, which substantially increases the ruggedness of our design. This is particularly important when loading heavy crankshafts (such as one shown in photo on Page 1)."

Since the 1990s, Adcole has also been using HEIDENHAIN linear scales as well to measure radius on its line of camshaft measuring machines. Adcole made this decision because the HEIDENHAIN scale assemblies were less expensive to incorporate into the Adcole gages than Adcole's earlier designs. HEIDENHAIN's model LIP 481s are Adcole's current linear scales of choice as they are well known as high quality exposed linear scales characterized by small measuring steps together with high accuracy for ultra-precision machines.

Integrated Measuring Machines *continued from Page 1*

The coefficient of expansion, or deviations from it, have a strong influence on the use of encoders that serve as the basis for measuring machine results. Encoders usually feature measuring standards of steel, glass or glass ceramic. The relevant literature provides data for the coefficients of expansion; however the data given differ significantly from source to source.

Their utility as a basis for length compensation is therefore limited, as becomes visible in the data for steel, for example. A temperature change of even a few degrees can result in deviations of several micrometers in compensation values calculated from an inaccurate coefficient of expansion.

$\Delta L = \alpha \times L \times \Delta T$		
Example: Steel		
Δ1K	Δ2K	Δ5K
α 11,0 ≈ 16,5 µm	≈ 33,0 µm	≈ 82,5 µm
α 11,6 ≈ 17,4 µm	≈ 34,8 µm	≈ 87,0 µm
α 12,2 ≈ 18,3 µm	≈ 36,6 µm	≈ 91,5 µm
Original length L = 1500 mm		

Possible methods of ascertaining the coefficient of expansion

A coefficient of expansion can be measured exactly by a dilatometer, which is a device for measuring thermal expansion. With a well-designed dilatometer, it is possible to attain exact data on a material's coefficient of expansion by measuring a test object and to use it to manufacture encoders. An example is the "alpha measuring station" for measuring the thermal length expansion of bar-shaped bodies. Such a measuring station has been set up at the *Physikalisch-Technische Bundesanstalt*, Germany's national metrological institute in Brunswick.

This exactly measured value can then be applied to calculate length compensation. In most cases, companies manage as best they can with data from the literature or the material manufacturer. This makes uncertainty in the result inevitable.

Temperature and accuracy compensation

Special care must be taken in setting up a shop-floor measuring machine. Years of experience by the manufacturer result in high reliability and ensure high accuracy in spite of harsh environmental conditions. No compromises in accuracy are made compared with machines in measuring rooms. Thermal effects must be dealt with through the appropriate know-how, the selection of suitable materials and providing for thermal requirements. Because temperature increases expand materials to different degrees and these materials take on the surrounding temperature at different speeds, complex calculations are conducted to compensate the effects of temperature and accuracy. A known basis for mathematical compensation is very important — the linear encoder.

You can't make a silk purse out of a sow's ear

Thermally stable encoders are an indispensible prerequisite for basing calculations on accurate measurement data and thereby achieving accurate compensation. The selection of encoder material for shop-floor measuring machine is therefore particularly important. While glass or steel scales permit only an approximate value for calculation, the expansion coefficient of 0+/- 0.1 x 10-6K-1ZERODUR® for glass ceramic scales remains accurate over a large temperature range, and the scales have proven to be very durable. The material is used the world over on telescopes, for example, because they place very high requirements on resistance to temperature changes and on distortion-free imaging.

Thermally stable encoders

The correct selection of encoders enhances machine characteristics and contributes significantly to the reliability of the measuring machine. The area of production-integrated measurement is characterized by the following requirements and characteristics:

- Encoders with defined coefficients of expansion
- High accuracy for deviation between compensation points
- Contamination for disturbance-free measurement
- High reliability over a long time period
- Cost-efficient encoders

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Integrated Measuring Machines *continued from Page 2*

The LIDA 400 exposed incremental encoder from HEIDENHAIN is characterized by high accuracy and customer friendly mounting tolerances, high traversing speed and the small height of the scanning head. These attributes make it well suited for use on production equipment in automation engineering and the electronics industry as well as for applications on linear drives and in many areas of metrology. Now, the introduction of new graduation carriers of glass and glass ceramics (ZERODUR®, ROBAX®) have greatly expanded the range of application covered by these encoders. They are therefore ideal for applications in shop-floor measuring machines. They are very easily installed by the PRECIMET® adhesive film on the back.

Because the standard scanning heads for the LIDA 400 meet all requirements for reading the scales of glass and glass ceramic (ZERODUR®, ROBAX®), no special scanning heads are needed. Also, the identical cross section of the scales allows the graduation carriers to be exchanged. From the logistical point of view this is a great advantage because the standard LIDA 48 (1 VPP) und LIDA 47 (TTL) scanning heads can be combined with glass ceramic and glass scales as well as with steel scale tapes. The identical carrier cross section of glass ceramic and glass scales make is easily possible to upgrade existing measuring machines. All designs have the same scanning surface of 14.5 mm², which ensures high tolerance to contamination and generates very clean scanning signals, which can be highly interpolated.

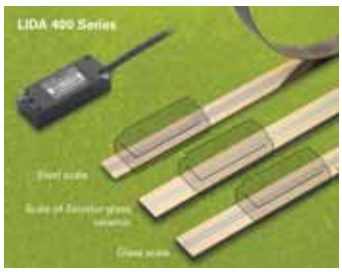
The encoders of HEIDENHAIN's LIDA 400 series have a grating period of 20 micrometers. They are available in the widely used 1VPP and TTL interfaces and for measuring lengths of up to 30 meters (steel) or 3 meters (glass and glass ceramic). Traversing velocities up to 480 m/min are easily possible. The encoders are available with reference marks as well as integrated magnetic limit switches.

Available measuring standards:

Material	Coefficient of expansion α_{therm}	Max. measuring length ML
	20 µm METALLUR graduation	
Glass	~ 8 x $10^{-6}K^{-1}$	3040 mm
ZERODUR® glass ceramic	**(0±0.1) x $10^{-6}K^{-1}$**	**3040 mm**
ROBAX® glass ceramic	~ 0 x $10^{-6}K^{-1}$	1640 mm
Steel	~ 10 x 10^{-6}·1	30 040 mm

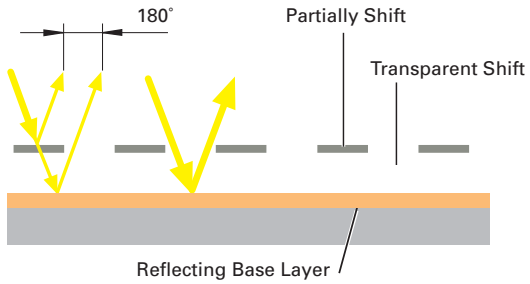
Summary

Today's changing requirements on machines such as measuring machines or production equipment in the electronics industry call for encoders that are also capable of meeting these demands. The problem of thermal expansion can be solved by the proper selection of different graduation carriers that are uniformly capable of using the same model of scanning head. In conjunction with measuring standards of glass and glass ceramic, the new generation of LIDA 400 exposed linear encoders offer ideal properties for accurate measurement even on shop-floor and in production-integrated machines.



The scanning heads for the LIDA 400 are a standard size, so they meet all requirements for reading the scales of glass and glass ceramic. Also, the identical cross section of the scales allows the graduation carriers to be exchanged.

METALLUR process
HEIDENHAIN has developed a process—known as the METALLUR process—for manufacturing graduations on glass, glass ceramic or steel. The quasi-planar graduation structure provides optimum protection against contamination and thereby greatly enhances encoder reliability. The manufacturing processes are environmentally friendly and are entirely without chemicals such as those generally needed for etching.



HEIDENHAIN and Semiconductor Machine Efficiency

By Kevin Kaufenberg, Product Manager, Electronics

Since my relatively late start in the semiconductor industry in the mid 90s, and even in this timeframe of a decade and a half, I've seen huge changes in this market segment with regard to production machine efficiency. Within a few short years, we all went from having large CRT monitors on our desk to one or even two or more flat panel monitors. The machines that build these flat panel monitors are so efficient as to flood the developed world with flat panels in an amazing amount of time.

The newly emerging solar market has machines that are pumping out panels at several hundred per hour and even versions that are printed almost like newspapers. Inspection tools, pick and place machines, wire bonders, dicing machines, lithography. The list goes on and on about how these various types of machines have been vastly improved over a relatively short time. One common thread in all this is the motion system that is at the core of these machines, a key part in the matrix of technologies that come together to make a machine. And in most cases within that motion system is a fast, accurate, high quality, long lasting HEIDENHAIN encoder.

Since speeds are being pushed to the maximum in this industry, HEIDENHAIN's R&D department is responding. With new ultra-low noise electronics that are approaching the quantum mechanical limits and higher power reliable light sources that are incorporated into encoders (such as in our LIP 200 series), HEIDENHAIN is ready to take on and overcome the industry demands of faster speeds. And now with the ENDAT 2.2 interface for our new LIC 4000 absolute kit style long length linear encoder system, we can provide digital absolute position at the same speeds as the fastest analogs could do just a few years ago.

Our dependence on efficient machines will only grow in the future. This phenomenon is spreading to other markets, like medically based machines for example, which can only have a positive effect on human health. Economic downturn or not, innovation will allow machine efficiency to improve and HEIDENHAIN will continue to innovate regardless of market conditions, ensuring that encoder technology will not be a stumbling block on the road to progress.

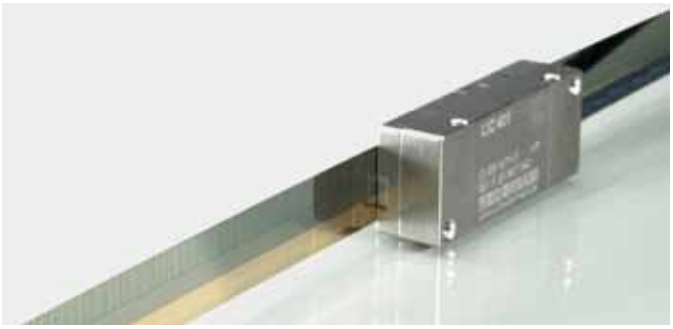
The Scale Tape Solution for a Wide Variety of Applications

HEIDENHAIN'S LIC 4000 Absolute Linear Encoder

Incorporating absolute technology to a multi-substrate scale tape linear encoder design, HEIDENHAIN introduces the versatile new LIC 4000. Besides its capability of absolute position measurement, this new encoder is characterized by its high resolution of 1 nanometer and its fast, purely serial EnDat 2.2 interface.

Absolute encoders, which provide the current position immediately upon switch-on, offer high technological reliability and safety because they can do without the reference runs that would otherwise be necessary. Absolute encoders are especially well suited for use on direct drives. Together with the current position, the commutation offset is known immediately upon switch-on and the motor can immediately be provided with power and held in the control loop. Critical operating states, such as switching on a vertical axis with direct drive or retraction after an emergency stop, are controlled safely.

Thanks to their specialized scanning technologies, these encoders with up to 27 meters of measuring length are insensitive to contamination and therefore guarantee a high degree of equipment availability and a high traverse speed,



while at the same time achieving a high resolution. The dimensions of the LIC 4000 match those of the HEIDENHAIN LIDA 400 incremental linear encoder, which has already successfully established itself on the market. This makes it possible to easily retrofit today's machines to absolute measurement technology by exchanging the encoders. Only the subsequent electronics must be adapted correspondingly.

Exposed linear encoders from HEIDENHAIN are characterized by their high accuracy together with customer-friendly mounting tolerances, high traversing velocity, and low height of the scanning head.

A New Way to Gauge High Accuracy with SPC

Combining a highly accurate CERTO length gauge with an ND 287 digital readout (DRO) equipped with Statistical Process Control (SPC) enables HEIDENHAIN Corporation to offer a powerful new inspection system to the market. Since the new universal HEIDENHAIN ND 287 also has a card for gauge hookup, it was certain to tie-in with CERTO, an established gauge capable of a large measuring range, including nanometer-level measurement. Common applications for this system are inspection of measuring equipment and gauge block calibration.

The length gauges of the HEIDENHAIN-CERTO program measure ranges of 25 mm at ± 0.1 µm/± 0.03 µm accuracy and 60 mm at ± 0.01 µm/± 0.05 µm accuracy, with the latter accuracies established after error compensation. It permits a significant reduction in the required number of reference standard blocks in inspection processes, and recalibrating becomes much simpler. Alternative inductive gauges have limited measure lengths and accuracies.

When combining HEIDENHAIN-CERTO with the new ND 287 single-axis position display with its many features designed to more fully integrate in a machine data transfer network, the new HEIDENHAIN system becomes an especially powerful tool. The ND 287 itself allows up to four inputs and allows toggling between multiple gauges, sensors and encoders to be done easily. The SPC function gives users the ability to write up to 10,000 measured values to an internal memory and evaluate them statistically.

And with the inclusion of HEIDENHAIN's CS-200 gauge stand with its highly polished granite surface, tight tolerances are ensured due to the shaft perpendicularity. A vacuum chuck option, consisting of a ceramic suction plate and a diaphragm pump, is available for this system to further increase accuracy by eliminating air gaps during the metrology process.

Introducing the new RENCO R28i Encoder

Now distributed and available through parent company HEIDENHAIN Corporation, the new RENCO R28i Modular Encoder is perfectly suited for size 11 step motor applications, providing state-of-the-art performance in a 28mm package.

The innovative design is self-aligning and self-gapping, and requires no special tooling for installation. The custom OPTO-ASIC provides a wide range of available resolutions, and sets the standard for resolution and performance.

This RENCO R28i can also accommodate motor shafts up to 7mm making it suitable for brush motor, step motor, and lead-screw applications.

To provide a robust mounting, the motor can utilize the existing motor assembly screws, or dedicated mounting points for durability and reliability.

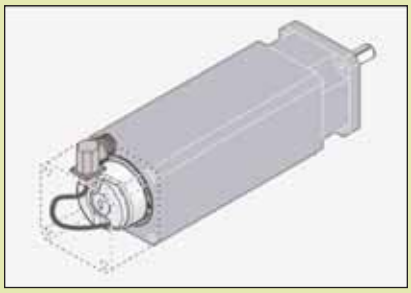
RENCO Encoders is a leader in the industry of high-quality modular and bearing encoders, offering a wide range of

standard and custom products and services that meet an array of motion control needs. RENCO Encoders, a California-based company, designs and manufactures all our products on site at the Goleta, CA facility.

Technical Tidbit:

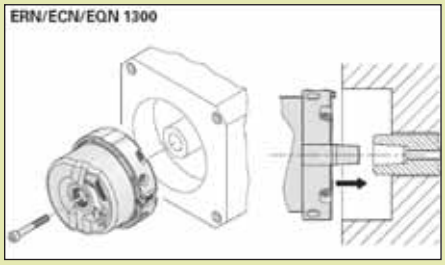
The Task of a Stator Coupling

In order to meet today's dynamic requirements on encoders with bearings and stator couplings, much design work and testing is necessary, especially for motor applications. The end result should be superior signal quality under the most demanding conditions. Stator couplings play a very important performance role here.



(Fig. 1)

The stability of a rotary encoder / drive encoder system, in large part, depends on the coupling design, material, material thickness, and form. The slightest change can and will affect the overall performance. In some cases, machine manufacturers will develop their own coupling for various reasons not realizing the changes it can cause in the overall dynamics. In every instance, these changes will have an adverse effect, damaging the encoder. (When special circumstances require adjustments, HEIDENHAIN can provide customized solutions.)



(Fig. 2)

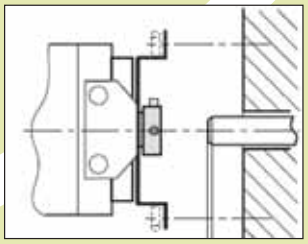
Think of the use of a stator coupling in this way: the rotary encoder along with the stator coupling form a vibrating mass system whose natural frequency should be as high as possible. Natural frequency is the frequency at which a system will begin to vibrate as it is set into motion. The goal is to make this frequency as high as possible while maintaining bearing life, signal quality and overall longevity. Not an easy task. Fig. 1 highlights a coupling design based on a servo motor application.

This unique design with mounted stator coupling and tapered shaft literally allows the encoder to become one with the motor. This design offers several benefits from a dynamic performance range to ease of installation ideal for mass production situations. The mounting process is quite simple. The tapered shaft of the encoder fits into the mating taper of the measured shaft (Fig. 2). This means the encoder is self aligning to the bearing and shaft of the motor. The only hardware required is the central mounting screw that brings the shafts together. The stator coupling of the encoder is clamped in the pocket by an axially tightened screw. As you can see in Fig 3, the screw forces the expansion of the coupling via two-nuts. At first glance, it may not seem rigid enough, however, the combination of tapered shaft and this style coupling has ~4x the holding torque than standard stator couplings. (Fig. 4)

(Fig. 3)

The task of a stator coupling goes far beyond just simply attaching the encoder to a measured shaft. In review of the benefits, we now know:

- No axial mounting tolerances between shaft and stator housing for this particular design
- High natural frequency of the coupling ≥ 1,800 Hz
- High torsional rigidity of the shaft coupling
- Lower profile, less real estate required for mounting
- Simple installation
- Up to ± 0.5 mm axial motion



(Fig. 4)

These are just some of the reasons why HEIDENHAIN leads the industry when it comes to quality and innovation.

Dear Abbé...

Providing answers to questions of accuracy

Question: What is a PWM 9?

Answer: The PWM 9 is a complete universal measuring unit for inspecting and adjusting HEIDENHAIN incremental linear and angle encoders. Instead of offering just a series of LEDs on the encoder for installation which can lead to a green light that could just be marginally green and cause issues after the machine has shipped to the customer, HEIDENHAIN offers two devices that provide detailed information on the encoder signals and allows the user to install correctly, thereby increasing the safety margin and quality of the machine overall.

First, the small low cost handheld device that displays amplitude information to a resolution of 0.1V and the quality of the home pulse is called the PWT. There are various PWTs for the various electrical interfaces and are dedicated to that interface, such as 1Vpp or TTL. The other device, a PWM 9, however has this PWT mode as well as much more detail about the encoder signals, such as phase angle of sine and cos waves, encoder current consumption and encoder voltage and offsets. The PWM 9 has a slot where various electrical interface cards can be inserted, such as Endat (incremental analog signals only), TTL, and 1Vpp. PWM 9 is German for Phasen Winkel Messung which translates to Phase Angle Measurement, and it is the 9th iteration of this device.

PWM 9 shown in PWT mode.

The PWM 9 is also valuable for safe inline usage so that a user can look at the detailed encoder signal parameters while the machine axis is put to motion. This helps the users to determine if the encoder is installed correctly and with enough safety margin through the whole range of motion of that particular axis. Encoders with LEDs cannot compare as one does not know if certain areas of the motion axis are marginally “green” or not. Encoders using just a USB interface for setup also cannot be run inline with the machine axis in motion.

The PWM 9 has a monochrome backlit LCD screen that is easy to read from any angle. It also contains 3 BNC sockets for testing encoder outputs on an oscilloscope, which is probably the best way to install encoders as the lisajous pattern is very visible and easy to interpret with the proper training.

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