The measuring accuracy specified for incremental linear encoders from HEIDENHAIN typically applies for a range of one meter. Many applications, such as on measuring machines, require shorter distances—for example, every 50 or 100mm. By calibrating the machine and compensating the error in the subsequent electronics, it is possible to significantly increase the machine accuracy. This process is particularly well established in coordinate measurement technology, motion platform manufacture, and plays a key role in ensuring high machining accuracy over large measuring lengths. Modern controls allow ten or more compensation values per meter traverse.

To calculate the expected measuring uncertainty of the machine, the machine manufacturer needs data on the maximum error to be expected between the compensation points.
Because nonlinear error components occur in incremental encoders and cause relevant error even over short ranges, the usual specification of measuring accuracy is insufficient. HEIDENHAIN therefore finds the expected residual error after sectional (multipoint) linear compensation for the encoder of the LIDA 400 series. Here the high accuracy and good signal quality of this encoder became apparent.

The accuracy of incremental linear encoders is comprised mainly of the position error over larger distance intervals and the position error within one signal period. With the LIDA 400, the position error over the measuring length is measured in a comparative measurement with a calibrated reference measuring device such as a laser interferometer. The measurement is recorded with a measurement interval of one millimeter. An example for the position error over the measuring length is shown in Figure 1.

Finding the residual error
HEIDENHAIN ascertains the position error after multipoint linear error compensation (residual error) at compensation point intervals A of 50 mm and 100 mm. The following example uses the distance A of 50 mm (see Figure 2). The compensation values are determined at n x 50, i.e., at 0, 50, 100, 150, etc. The values between these points are then interpolated. The following multipoint linear compensation eliminates the error at the respective compensation points. The curve in Figure 3 shows the residual deviations after multipoint linear compensation.

The maximum residual deviation
Of course, the residual error determined in this way greatly depends on the position of the compensation points. To find the actual maximum residual error, the compensation points are each shifted by one millimeter and the compensation values for the positions 1, 51, 101, etc., to 49, 99, 149, etc., are recorded. As in the above example, for these points as well the residual error is recorded and the maximum absolute value of the residual error is calculated from the large number of error curves.

This method ensures that the specified maximum error after multipoint linear error compensation is independent of the position of the compensation points.
Position error \( u \) within one signal period

Accuracy evaluation of the entire encoder must also include the position error within one signal period. This error is determined by the quality of the measuring standard and the scanning as well as the signal period of the encoder. On the LIDA 400, when mounted according to the Mounting Instructions, it is typically \( \pm 1\% \) of the signal period. For a signal period of 20 \( \mu m \), the position error within one signal period is calculated at \( \pm 0.2 \mu m \). The range of error, here 0.4 \( \mu m \), is used for further calculation.

Resulting position error

The resulting error \( F_{total} \) after multipoint linear compensation therefore consists of the maximum residual error over large length intervals \( F_{residual} \) (depending on the compensation point interval) and the position error \( u \) within one signal period: \( F_{total} = F_{residual} + u \).

For the LIDA 400 in this example, the following typical values were calculated:

At a compensation point interval \( A \) of 50 mm:

\[
F_{total} = 0.8 \mu m + 0.4 \mu m
\]

\[
F_{total} = 1.2 \mu m
\]

At a compensation point interval \( A \) of 100 mm:

\[
F_{total} = 1 \mu m + 0.4 \mu m
\]

\[
F_{total} = 1.4 \mu m
\]

Conclusion

With its specification of the resulting length error after multipoint linear error compensation, HEIDENHAIN provides the machine builder with an important index. It allows the skilled manufacturer to prepare a good assessment of the measuring uncertainty to be expected, and at the same time indicates the high accuracy of the linear encoder from the LIDA 400 series.

For more information, circle #2 on the reader service card.
The development of small hydrogen targets to test thermonuclear ignition is like a science in itself. Or so says Ken Abbott, the owner of the company that manufactured the custom air-bearing motion system that builds those targets. This new custom machine from his company, ABTech (www.abtechmfg.com) in New Hampshire, is now in place at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), and has recently passed inspection to begin its work.

LLNL is at the University of California (employing 8,000 people) and is federally funded to do research in a variety of areas, including nuclear power, national defense and the environment. The NIF lab is currently on track to house the world’s largest laser, which will involve 192 individual laser beams that will be repeatedly trained onto high precision tiny hydrogen targets. With each test, a double shell implosion target will be placed in a 30-foot diameter chamber with the laser beams fired simultaneously to explode it, demonstrating thermonuclear ignition. Its output will be measured for use in a variety of ways.

The manufactured hydrogen targets themselves each use capsules of fusion fuel, and are heated to thermonuclear ignition. The targets are made of a silica-based inner sphere, and the manufacturing requirements for surface finish and shell concentricity of the targets are essential to successful explosion. The shell halves are assembled on ABTech’s custom 5-axis air bearing assembly station in order to achieve acceptable concentricity.

Weighing about 150 pounds, this air-bearing machine system includes mechanical arms that can slide, without friction, into position, with accuracy as little as 4 millionths of an inch. “Each target is 28 thousandths of an inch in size, smaller than the top of a ballpoint pen,” said Abbott.
The overall components of this unique machine include three linear air bearings and two rotary air bearings, a motion controller, a host PC and application software. The system is capable of positioning the target shell halves to locations within 0.1 µm. “The only way this is now possible is with the use of today’s ultra-precise linear scales for use on the linear slides,” explained Abbott, “and because of the strict accuracies required in NIF’s specifications, our only choice was the extremely high accuracy LIP 481 scales from HEIDENHAIN Corporation. It’s really amazing what they can accomplish today.”

The HEIDENHAIN LIP scales are exposed linear encoders characterized by high accuracy together with measuring steps as small as 0.005 µm, depending on the model. Their measuring standard is a phase grating applied to a substrate of glass, and they are typically used in the highest precision machines, such as diamond lathes for optical components, facing lathes for magnetic storage disks and measuring microscopes and semiconductor equipment machines.

The ABT ech air-bearing system at NIF includes three of these ultra-precise HEIDENHAIN scales, one on each of the X, Y and Z linear axes. The entire system is completed with a high resolution camera and surgical microscope that provide views of the mating components.

The new system’s bearings produce a thin film of air similar to the layer of air that allows a puck to move smoothly across an air hockey table. Precision manufacturing takes place from there.

“This ABTech machine is a significant improvement from what NIF was using to develop early stage targets,” continued Abbott. “Our project is a complicated device, having taken about eight months to develop. Because of the high accuracies, it was crucial that we received assistance from the HEIDENHAIN representative. His highly technical expertise was instrumental in helping with the installation alignments. This machine is now truly like no other.”

With the new hydrogen targets, NIF’s experiments promise to produce temperatures and densities like those present on the sun or in an exploding nuclear weapon. These experiments will help scientists sustain confidence in nuclear energy without doing actual nuclear weapons testing (stopped in the United States during the 1970s), as well as produce additional benefits in basic science and fusion energy research.

For more information, circle #3 on the reader service card.
HEIDENHAIN Introduces the LIDA 200 Linear Encoder for Low Cost Motors

For straightforward motion applications where primarily simple and fast mounting of a small encoder is decisive, HEIDENHAIN now offers a new high quality, low cost exposed linear encoder package, the LIDA 200 series. These new exposed linear LIDA 200s offer two ways of simple mounting and are perfect for the low-end linear motor market.

In these applications, accuracy requirements are considerably lower than high-end applications such as in the semiconductor industry, where HEIDENHAIN’s established higher accuracy encoders are commonly used. HEIDENHAIN’s new LIDA 200s maintain the high quality graduations, accuracy and reliability of the LIDA 400, while offering a perfectly desirable grating period of 200 µm for analog systems (for digital systems, signal periods of 5 µm, 1 µm and 0.5 µm are available).

The LIDA 200 encoders can be simply and quickly mounted via a scale tape, which is supplied in rolls with reference marks and cut to the desired length by the customer, then secured directly on the mounting surface by means of its adhesive film. As an alternative, it can also be mounted by means of a scale tape carrier extrusion, along with supplied adhesive and clamping mechanism for thermal effects.

HEIDENHAIN’s new LIDA 200 linear encoders also actually operate at higher speeds (10 meters per second) than the LIDA 400, and boast even more resistance to contamination, e.g., like scratches and fingerprints, because of the coarser grating.

Technical Tidbit: Mounting Tolerance Flexibilities

The mounting tolerances of linear scales have an influence on output signals.

First, it is important to note that very small signal periods usually come with very narrow mounting tolerances for the gap between the scanning head and scale graduation. This is the result of diffraction caused by the grating structures. They can lead to a signal attenuation of 50% with a gap change of only ±0.1 mm. Thanks to the interferential scanning principle and innovative index gratings in encoders with the imaging measuring principle, it has become possible to provide ample mounting tolerances in spite of the small signal periods.

The mounting tolerances of exposed linear encoders from HEIDENHAIN have only a slight influence on these output signals. In particular, the specified gap tolerance between the scale and scanning head (scanning gap) causes only negligible change in the signal amplitude. This behavior is substantially responsible for the high reliability of exposed linear encoders from HEIDENHAIN. The two diagrams illustrate the correlation between the scanning gap and signal amplitude for the encoders of the LIDA 400 and LIF 400 series.
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For further information, circle the appropriate number:
Article #1 #2 #3 #4 #5 #6 #7

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333 E. State Parkway, Schaumburg, IL 60173
Phone: 847/490-1191 FAX: 847/490-3931

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ELECTRONICS VOLUME 1
In order to meet the needs of various industries for angle encoders without bearing that feature higher accuracies and large hollow shafts, HEIDENHAIN Corporation now introduces its expanded series of new ERA 4000 angle encoders. Perfect for use on a wide range of rotary motion systems, spindles, and other motors, this family of encoders boasts legitimate incredibly high accuracies, multiple unique easy and stable mounting methods and reference marks that can be distance-coded to provide semi-absolute positioning.

The newest family member, the ERA 4x80 version, is mounted using a centering collar method. This low-profile encoder system does not require centering methods as the precision-machined centering collar mates with the precision-machined shaft of the motion system. With seven standardized diameters, system accuracies are offered with the 20 µm grating period version from +/- 6.1 arc seconds on the smallest diameter to +/- 2.8 arc seconds on the largest diameter.

The second family member, the ERA 4x81 version, is the weight reduced T profile version which is mounted using the three-point centering method. These three centering marks are placed on the ring at 120-degree intervals to point to the exact center of the ring while it is on the ultra-precise HEIDENHAIN manufacturing device, and then the encoder gratings are written onto the ring so that when the centering marks are used during installation, noncircular geometries of the ring and gratings are eliminated. Encoder system accuracies of +/- 8.6 arc seconds are offered with the smallest diameter of the series using 20 µm grating period and +/- 2.8 arc seconds for the largest diameter in this group.

The third family member, the ERA 4x82, uses the three-point centering method for installation and has the highest accuracy of the series. This version with the same inertia as the ERA 4x80, but without the centering collar, offers system accuracies from +/- 5.1 arc seconds to +/- 2 arc seconds for the largest diameter.

All three family members use the same scanning unit per diameter and have a movable faceplate, thus allowing for the best signal possible to be obtained via small, easy adjustments. The faceplate will maintain position even under the toughest machine vibrations.

The ERA 4000 series is available in seven different diameters, ranging from an outer diameter of 52.65 mm to 331.31 mm and grating periods of 20, 40 or 80 microns. The electrical output is available in 1-Volt Peak to Peak analog interface.

For more information, circle #5 on the reader service card.
Equipped with advanced Single-Field Scanning technology and incorporating all the latest developments in linear measurement technology, HEIDENHAIN is now making available their latest sealed linear encoders called the LS XX7 Series. These new scales are available up to 3m in length, come in two different mechanical profiles and offer unparalleled resistance to contamination and vibration, making them particularly useful in dynamic machine tool applications.

This new single-field scanning technology provides significant encoder advantages regarding the tolerance to contamination and to electromagnetic noise sources. Along with this improved signal stability, single-field scanning also has proven to improve signal quality, providing a typical output signal error of ±1 % within one signal period.

Along with offering an improved encoder, simple mounting methods are standard with these HEIDENHAIN LS linear encoders in order to incorporate them into a wide variety of applications. Encoders of the LS 400 series can now utilize a universal mounting spar when required, which allows for a cable outlet to the left or right. Available accessories also include clamps, as an alternative that are mounted at fixed intervals along the measuring length to provide additional support.

Encoders of the LS 100 series have left and right cable outlets directly on the scanning unit. The unused socket connector is protected by a cap, and both encoders of the new series utilize the same cable assembly.

For more information, circle #6 on the reader service card.
Dear Abbé…

This column promises to answer questions related to accuracy issues in measurement. HEIDENHAIN welcomes your questions.

Dear Abbé,

I keep hearing about this term “short wave error”; what does that mean?

Sincerely,

Curious

Dear Curious,

Short wave error, otherwise known as interpolation error, is inherent in every measurement encoder. This is the error that is found within one signal period, and for standard HEIDENHAIN encoders, the value of this error is typically 1% of the signal period.

A signal period of a typical linear motor encoder is 4µm and is represented by one cycle of the sine or cosine wave output and equals one count. Interpolation of the signal period is required if higher resolution is needed for positioning and speed control. Interpolation simply means that the 4µm signal period can be divided electronically into smaller counts. Typical interpolation values are anywhere from 2 to 4,096 times and higher.

Interpolation requires a digitization of the analog sine and cosine waves coming from the scanning unit.

A graphical representation of this can be realized by displaying the analog sine and cosine signals on an oscilloscope. The resulting figure on the oscilloscope is a circle (when the encoder is moving and generating counts) and is called the Lissajous figure. Interpolation works by dividing up this circle by the same number of interpolation, i.e., 100 fold interpolation divides the circle into 100 separate pieces. Electronics calculate an angle along this circle, and when the encoder is scanning and the correct angle is achieved, an edge of a digital square wave is output. The final output is a square wave signal for sine and cosine, typically TTL or a serial word.

If the Lissajous figure is not perfectly circular (See Figure 1), then the arc tangent calculation used to calculate the angle will be erroneous due to the non circular Lissajous figure. This affects the edge-to-edge spacing in the digital signal and results in position error, or short wave error. Some phenomena that cause a noncircular Lissajous figure are poor alignment of the encoder, contaminations on the encoder scale, and local environmental effects like electromagnetic noise. As stated before, if the Lissajous figure is circular, then the expected error is 1%. Special encoders exist with upgraded encoder electronics to enhance the signal quality, and error can be reduced to 0.1% of the signal period.

Figure 1.

In the XY representation on an oscilloscope the signals form a Lissajous figure. Ideal output signals appear as a concentric inner circle. Deviations in 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 with the amplitude of the output signal, can vary within certain limits without influencing the measuring accuracy.

For more information, circle #7 on the reader service card.
On behalf of all of HEIDENHAIN Corporation, I want to thank all of our customers and associates for their business during HEIDENHAIN's first year of a positive corporate restructuring. January 1, 2006 saw the introduction of an internally market-segmented HEIDENHAIN, and this January 1, 2007 completes the restructuring with the announcement of three National Sales Managers.

As many of you know, the division of activities by Market Segment at HEIDENHAIN was done to better meet the needs of those we serve. Those Market Segments are Machine Tool (which includes metalworking), Electronics (which includes semiconductor, medical and metrology) and Automation (which includes drive technology). Each area also covers its relevant aftermarket and re-seller needs. Any machine that needs motion control will fall into one of these market categories.

And when they do, our customers can rest assured that one of our three recently promoted Sales Managers will help to service their needs. Each of these three managers have a high degree of product and market knowledge, as well as application experience, in their respective areas. Their extensive knowledge of motion control applications and HEIDENHAIN products was instrumental in their selection as the Sales Division heads for their respective markets.

Each of these managers has been with HEIDENHAIN for many years, and all were most recently product managers. They are now responsible for each division’s sales segments as well, and will report directly to me.

It is also important to note that each of these managers is a direct liaison to HEIDENHAIN’s development departments in Germany, thus giving our customers a direct voice to the R&D group.

We believe all of this will continue to benefit our customers, and we’re working hard to make sure it does. Please feel free to contact any of our new Sales Managers if you need any assistance.

The new Sales Managers are:

**Chris Weber**
National Sales and Product Manager
Machine Tool Division

**Tom Wyatt**
National Sales and Product Manager
Automation Division

**Kevin Kaufenberg**
National Sales and Product Manager
Electronics, Semiconductor & Metrology Division

By Rick Korte
President, HEIDENHAIN Corporation