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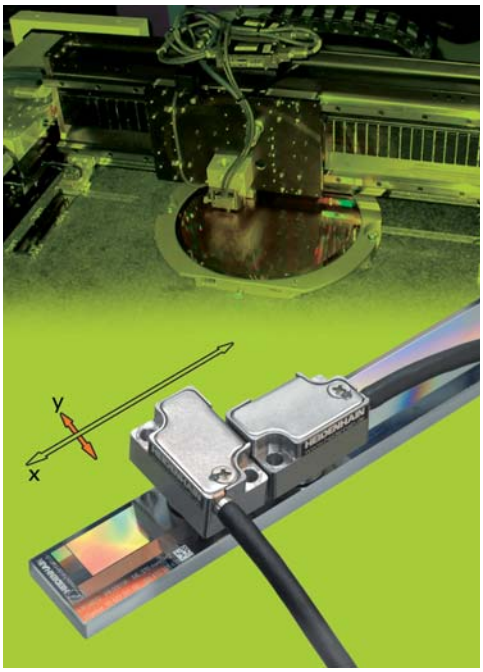
A New Dimension in the Nanometer Range

The trend in the semiconductor industry to ever higher levels of integration and, with it, to continuously finer structures, calls for measuring devices with high resolution for positioning to the nanometer in the manufacturing process and in measuring and inspection technology. Measuring error due to guideway influences and thermal expansion, which at present cannot be compensated by computation, can be ascertained by a new measuring device and therefore significantly reduced. "To purposefully change something, you must first be able to measure it."

Source: "Crash Course in Nanotechnology," keynote speech by Dr. Alois Rhiel, February 2006.



LIF 481 1Dplus encoder

Encoders with high resolution

The concept of nanotechnology is used for a number of technologies that involve structures and processes in the nanometer range, and it is considered a key technology of the 21st century. A nanometer is a billionth of a meter (10^{-9} m) and denotes a limit range in which quantum physical effects begin to play an important role. Nanotechnologies such as those seen in optical and semiconductor manufacturing use machines as well as measuring and testing equipment with high positioning accuracy and repeatability. The specified values lie in the range of 100 nm to 1 nm and even smaller.

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Did You Know...

…that HEIDENHAIN angle encoders are vital components in much of the largest array of telescopes of its type in the world, serving as the basis of a large astronomy research and training ground in the upper mountains of eastern California? Known as **CARMA** (the Combined Array for Research in Millimeter-wave Astronomy) this university-based (five universities) millimeter array consists of 23 telescopes and is operated daily with students and young scientists (www.mmarray.org). The science with CARMA centers around the study of the cold universe through imaging of radio emissions from molecules, dust, and relic emission from the very early universe. Funding is provided from the National Science Foundation and member institutions.

Of the 23 telescope antennas on site, HEIDENHAIN's RCN 729 angle encoders have been retrofitted into the six 10.4 meter antennas (the largest telescopes on the site), as well as chosen for the eight newer 3.5 meter antennas. All the antennas are Altitude – Azimuth mount telescopes, having two axes each, and are used in combination to image the astronomical universe at millimeter wavelengths. "These HEIDENHAIN encoders allow us to accurately point on the sky," explained David Woody, Director of Instrumentation at CARMA. "The accuracy we achieve is 1 to 2 arc seconds."

Because of its high static and dynamic accuracy, HEIDENHAIN's **RCN 729 angle encoders** with large hollow shaft diameters are often the preferred units for rotary and angle measuring tables, indexing fixtures, measuring setups and image scanners. The stainless steel version is particularly useful in antenna applications.

"We chose the HEIDENHAIN encoder because we knew it could do the job we needed, and be reliable as well as very economical" said Woody. "They have proven to work out very well for us."

CARMA telescopes

For more information, go to www.heidenhain.us/el1 ■

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The encoders in these machines are subject to very stringent requirements for signal quality and accuracy. These requirements are met by laser interferometers or interferential optical encoders as position measuring devices. Both already offer very high resolutions well below 1 nm. Laser interferometers can be simply aligned with the tool center in order to eliminate Abbe error. One of the most serious disadvantages of these devices, however, is their dependency of the wavelength of laser light on environmental parameters such as temperature and air pressure. These have to be carefully measured along the interferometer's optical path and the error must be continuously compensated. Any fluctuation, be it ever so small, of temperature, air pressure, the composition of air and similar parameters ultimately results in a change in the wavelength of light and leads over a measuring length of 500 mm to position fluctuations in the order of 50 nm. The alignment error of the laser, which changes over time, lead to cosine or Abbe error that has to be calibrated continuously.

Stable measuring standards normally have a defined thermal behavior and are independent of air pressure fluctuations. In recent years, the LIP, LIF and PP product families from HEIDENHAIN have established themselves as stable measuring standards. The interferential scanning principle behind them exploits the diffraction and interference of light on a fine graduation to produce signals used to measure displacement that are therefore insensitive air fluctuations. A relative motion of the scanning reticle to the scale causes the diffracted wave fronts to undergo a phase shift: when the grating moves by one period, the wave front of the first order is displaced by one wavelength in the positive direction, and the wavelength of diffraction order –1 is displaced by one wavelength in the negative direction. Since the two waves interfere with each other when exiting the grating, the waves are shifted relative to each other by

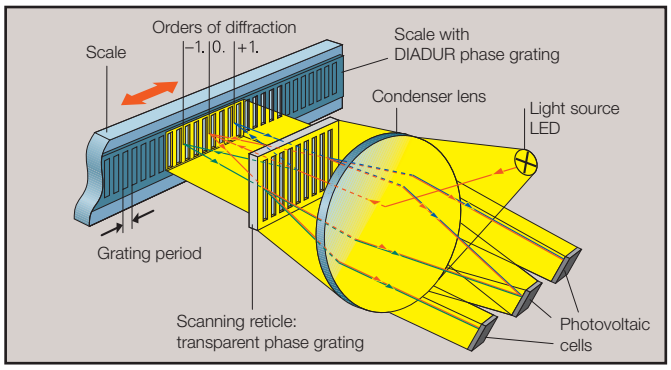

Figure 2: Interferential measuring principle

two wavelengths. This arrangement results in two signal periods from the relative motion of just one grating period. Interferential encoders function with grating periods of, for example, 8 µm, 4 µm and finer. Their scanning signals are largely free of harmonics and can be highly interpolated. These encoders are therefore especially suited for high resolution and high accuracy and a very high inherent repeatability. Even so, their generous mounting tolerances permit installation in a wide range of applications.

Influence of guiding error

All linear bearings have angular guiding error (pitch, yaw and roll) and linear guiding error (straightness, flatness). The error typically lies in the range of 5 to 100 µrad or 0.5 to 5 µm. The relevant statistical dispersion of this error is only a fraction of these values and is very small for air bearings. Angular guiding error leads to local tilting and, with an Abbe offset other than zero, to a length offset of the encoder and thereby influences the machine accuracy.

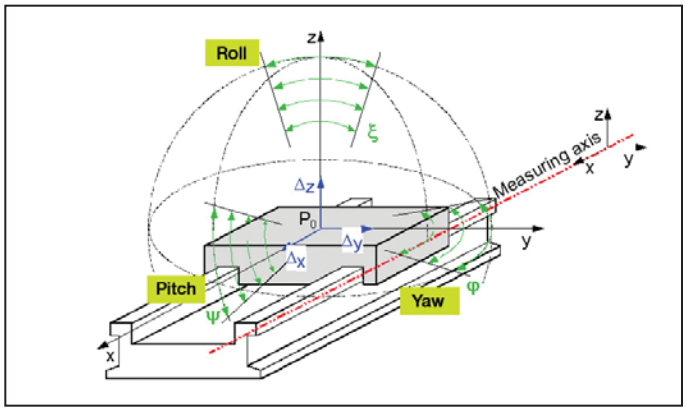

Figure 3: Influence of guiding error

Temperature as "spoilsport"

Although increasing temperature within a certain range improves people's wellbeing, temperature fluctuations are true spoilsports for measuring and testing technology in regard to accuracy and reproducibility.

Under temperature fluctuation, the accuracy of the system remains limited in spite of expensive designs and materials or additional measures (such as active cooling). Thermally induced geometrical changes of the machine can be mathematically compensated, if only with limitations.
The value of temperature measurement via sensor for linear compensation of thermally induced expansion depends upon
- the quality of the sensors used
- the correct placement (e.g. with inhomogeneous temperature distribution)

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Technical Tidbit:

Effect of Eccentricity

When installing an exposed angle encoder, one of the biggest factors affecting accuracy is mounting eccentricity to the center of rotation.

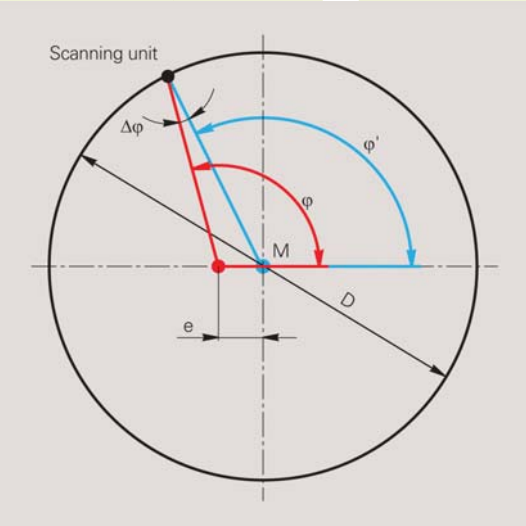
Error due to eccentricity of the graduation to the bearing

Under normal circumstances, the graduation will have a certain amount of eccentricity to the bearing after the disk/hub assembly (ERP), circumferential-scale drum (ERA 4000) or scale tape (ERA 78x C and ERA 88x C) is mounted. In addition, dimensional and form deviations of the mating shaft caused by the positioning of the centering collar can result in added eccentricity. The following relationship exists between the eccentricity e, the mean graduation diameter D and the measuring error $\Delta\varphi$.

$$\Delta\varphi = \pm 412\ e\ /\ D$$

$\Delta\varphi$ = Measuring error in " (angular seconds)
e = Eccentricity of the radial grating to the bearing in µm
D = Mean graduation diameter (ERP) or drum outside diameter (ERA 4000) and scale-tape carrier diameter (ERA 78x C/ERA 88x C) in mm
M = Center of graduation
φ = "True" angle
φ = Scanned angle

Eccentricity of the graduation to the bearing

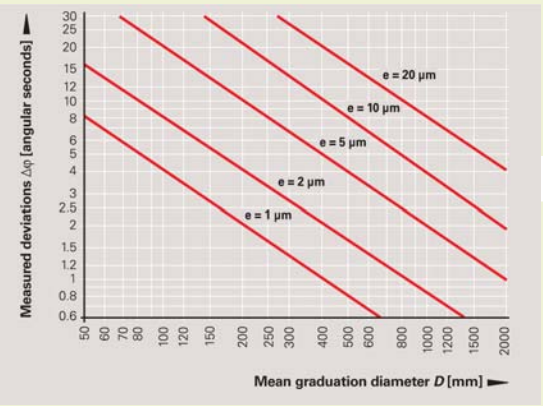


If we take the example of an ERA 42XX with an OD of 127.64 mm and a line count of 20,000, the specified accuracy of the graduation is 3.7". If we installed this device with 2µ (0.002 mm) of eccentricity, the following additional error would be added.

$$\Delta\varphi = \pm 412 \cdot e / D$$
$$= \pm 412 \cdot 2/127.64$$
$$= \pm 6.45"$$

The chart to the right can be used as a quick reference to calculate the effect of eccentricity at various ODs with various deviations. ■

Resultant measured deviations $\Delta\varphi$ for various eccentricity values e as a function of mean graduation diameter D



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- the aging of the sensors, and
- in addition, calibrated temperature sensors must be continuously monitored and, if required, replaced with sensors with the same properties.

Linear motors are also heat sources, especially on fast machines, and can cause thermomechanical deviations. Because of their complex designs, gantry axes require special examination in this regard. The influence of guiding error and thermal changes presents great challenges on the road to nanometer-exact positioning within manufacturing processes and in measurement and testing metrology. A new type of measuring device from HEIDENHAIN can contribute to meeting them.

LIF 481 1D*plus* Encoder

Decades of experience in the field of microstructuring, together with corresponding equipment for scale carrier manufacture and modern structuring and production machines, similar to those found in semiconductor manufacturing, have combined to fulfill the market demand for a quasi two-dimensional measuring device.

Besides the usual longitudinal track (x axis) with the interferential graduation of the familiar LIF (4 µm signal period), the LIF 481 1D*plus* features an additional y axis track perpendicular to it. This nevertheless does not require eliminating of the reference mark on the longitudinal track. As is usual at HEIDENHAIN, the absolute position on the scale, established by the reference mark, is gated with exactly one measuring step. The glass ceramic ZERODUR® is used in a graduation carrier whose expansion coefficient of 0+/- 0.1 x 10^{-6} K-1 is exact over a large temperature range and is characterized by high resistance to aging.

With the appropriate arrangement of two or three scanning heads (Figure 5) the LIF 481 1D*plus* linear encoder makes it possible to measure and compensate linear and angular guiding error or the influences of thermal expansion:

Figure 4: LIF 481 1Dplus, a new type of encoder with x axis and additional y axis

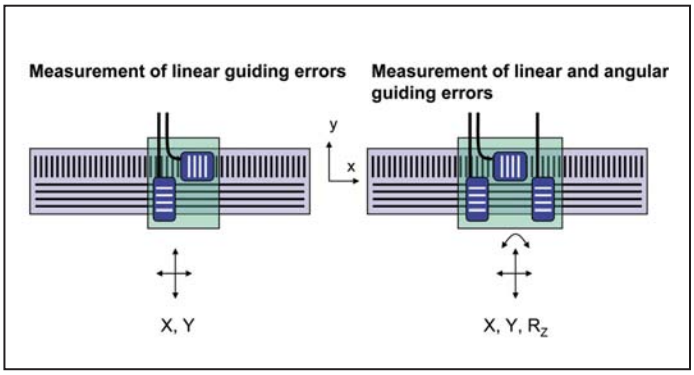

Figure 5: Arrangement with 2 or 3 scanning heads

Recording the "real-time condition" and compensation of the actual measured values contribute significantly to the improvement of positioning accuracy in the nanometer range. These ambitious expectations of the encoder were confirmed with the impressive results of an experiment.

Test setup

Figure 6 shows an example of the user of 1D*plus* scales on a gantry-type milling machine. The x axis is equipped with two heads H_{X1}, H_{X2} in an example arrangement of the scales. If the tool center point (TCP) is also aligned in Z to the centers of rotation H_{X1} and H_{X2}, all Abbe offsets of the X axis are equal to zero. The heads H_{Y1} and H_{Y2} detect straightness error (y) of the X guideway axis and, to an extent, the influences of thermal expansion. On the Y axis the heads H_{X3} and H_{X4} can be used for compensation of straightness errors in the X axis and Abbe error in the X axis.

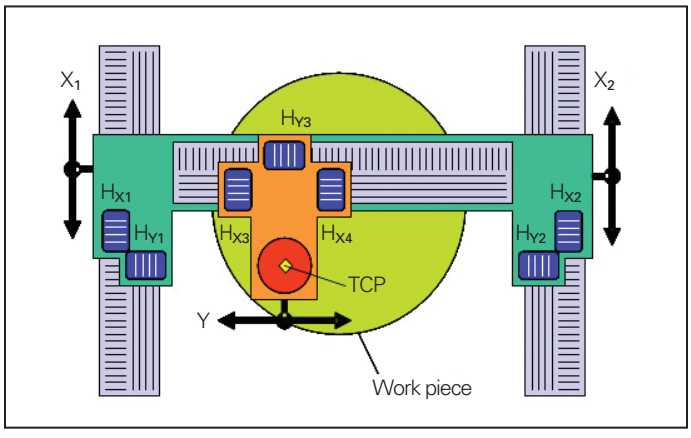

Figure 6: Gantry arrangement with LIF 481 1Dplus

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Dear Abbe...

Q: "With HEIDENHAIN's new high speed exposed encoder, the LIP 200, how are you able to loosen the mounting tolerances, especially in the rotation around the Z axis, all the while maintaining accuracy?"

A: Yes, you are right, HEIDENHAIN is able to easily loosen the mounting tolerances of the LIP 200 encoder in the Z axis rotation, otherwise known as yaw or Moire angle. The LIP 200 graduation is a 2µm graduation with a 0.5µm signal output. To do so, one would think that you would have to manipulate the Z-axis rotation in the same realm, smaller than 2µm increments. After all, Figure A shows that if the reticle graduation is not aligned to the scale graduation, you get a sort of "X" pattern, which does not result in quality signals coming from the scanning unit. Aligning a 2µm scale graduation to a 2µm reticle graduation is difficult when you consider humans must make the tiny adjustments with tools. Doing this alignment would take hours under normal circumstances.

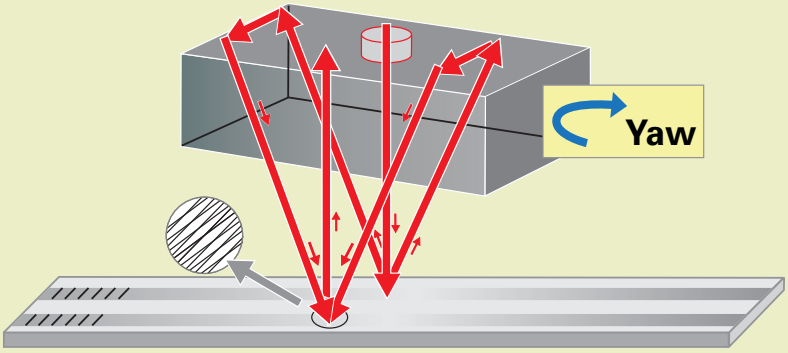

Figure A: Mount with Yaw of Scanning Head – no Compensation

However, HEIDENHAIN R&D has been able to make use of some little known optical principles in the design of the LIP 200 series encoder. Using specially formulated prisms, the optical effect is a bit like standing in front of a three-fold mirror system. Your image really never changes position, even when you might move left or right. Integrating this type of optical path, called the Optical Moire Compensation, and using two incremental tracks as shown in the images, the image of the scale graduation doesn't really change much with the yaw angle shown (Figure B). This allows a greater tolerance to the yaw angle of alignment, to a maximum of almost one-half a degree in either direction. This allows for a much easier alignment on the production floor, saving time and grief. It is possible to align the scanning unit with the right 2mm gap, align the yaw angle, and be in alignment to measure picometer level measurements on average of 2 minutes or less.

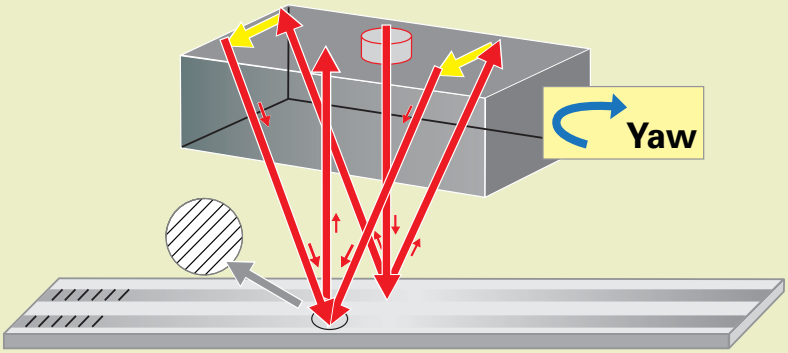

Figure B: Mount with Yaw of Scanning Head – Moire Compensation

Sincerely,
Abbe

If you have a question for Abbe, please send it to us at www.heidenhain.us/el1 ■

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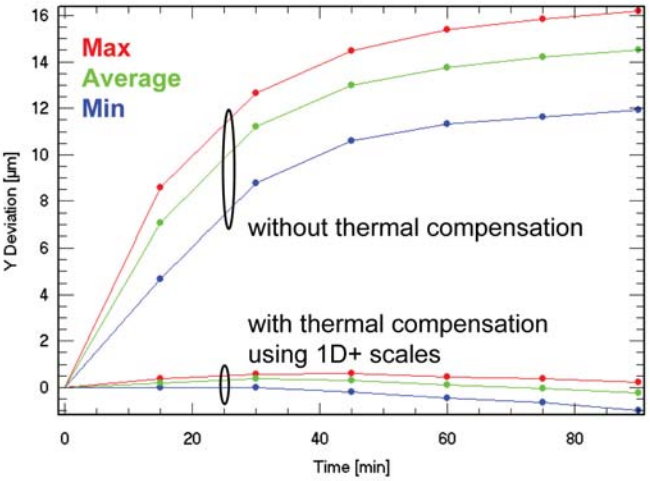

Figure 7: Incremental heating X and Y with fast reciprocation (acceleration = 1 g)

Summary
The inherent repeatability of today's interferential encoders with high resolution is far higher than that of interferometers in air. The effective measuring point of technically perfected encoders is stable and is hardly influenced by tilting. Encoders with 1D*plus* scales, which feature an additional perpendicular track, contribute to the reduction of Abbe error and the influences of linear guiding errors and thermal expansion. The additional track provides the information required for compensation in the perpendicular direction and for angular correction.

Literature:
Proceedings of the 6th euspen International Conference - Dr. W. Holzapfel - May 2006

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For more information, go to www.heidenhain.us/el1 ■

HEIDENHAIN's 2009 North American Exhibitions

See what's new and exciting in the precision measurement/motion control industry by visiting HEIDENHAIN on the road this year! ■

Lab Automation
January 25-27
Palm Springs Convention Center
Palm Springs, California

ATX (Automation Technology Expo)
Feb.10 -12
Anaheim Convention Center
Anaheim, California

Motor, Drive & Automation Systems Conference
March 3-4
Hilton Hotel at Walt Disney World
Orlando, Florida

TECMA
March 10-13
Expo Bancomer Santa Fe
Mexico City, Mexico

WESTEC
March 30 – April 2
Los Angeles Convention Center
Los Angeles, California

EASTEC
May 19-21
Eastern State Exposition
Springfield, Massachusetts

SEMICON
July 14-16
Moscone Center
San Francisco, California

Design & Manufacturing Midwest
September 22-24
Donald E. Stephens Convention Center
Rosemont, Illinois

HEIDENHAIN's Revolutionary 2-Dimensional Encoder

HEIDENHAIN's LIF 400 1Dplus interferential-type linear encoder

Introducing an exciting new dimension to measurement, HEIDENHAIN Corporation presents the 1D*plus* encoder. After much R&D, this uniquely innovative two-dimensional encoder was designed in order to allow measurement of linear guiding and thermal drift errors during movements of a stage or machine, allowing the processing and immediate compensation of these errors. This results in a system with very high accuracies with jobs done right the first time.

The most likely current applications for the 1D*plus* include use in stacked stages, precise gantries, wafer processing, and in large flat panel display production and tests, though any motion stage user who wants to increase performance would benefit.

These truly revolutionary 1D*plus* encoders are frictionless and have gratings in two dimensions, with models featuring two or three scanning units for simultaneous measurement of both the X and Y directions. Three scanning units allow the calculation of the angle of rotation of the bracket that houses the scanning units. These orthogonal encoder graduations provide an exciting new dimension in precision as the encoder system measures left and right (X axis), the up-and-down (Y axis) motion is measured (and compensated for by the control) as well.

HEIDENHAIN's early and current 1D*plus* encoders are in use as the HEIDENHAIN interferential-type linear encoder, the LIF 400 with 1D*plus*. The measuring standard is DIADUR with a thermal expansion coefficient of 0 ppm/K. Current measuring length is 300 x 2 mm, with plans to increase that dramatically. The 1D*plus* scale itself is 20 x 4.9 mm.

The X-axis measurement of the1D*plus* has a current accuracy grade of ±1 µm and includes a reference mark. The grating period of the encoder is 8 µm; the signal period is 4 µm.

For more information, go to www.heidenhain.us/el ■

HEIDENHAIN Thinks Green

By Kevin Kaufenburg
National Sales and Product Manager, Electronics

HEIDENHAIN evolves right along with the many industries it currently serves since, fortunately, measurement and feedback of motion improves over time. As the energy industry seems to be moving to a new state, HEIDENHAIN is right there with the correct, accurate feedback solutions to assist in the processes.

For example, with regard to wind energy, HEIDENHAIN and its sister companies, like RENCO, Leine & Linde and LTN to name a few, are enjoying business by providing the necessary feedback devices for the wind turbines. You can imagine that these turbines are in tough environments: lightning, excessively high winds during storms, humidity, large temperature swings, etc. HEIDENHAIN's families of encoders are tested internally to those same specifications and more, thereby providing long lifetime in these harsh conditions.

On the renewable energy source of light from the sun, photovoltaic production and solar tracking are also popular applications for HEIDENHAIN currently. Solar concentrators and trackingphotovoltaic cells need to follow the sun to obtain maximum efficiency. The motion control systems involved also often use HEIDENHAIN family rotary feedback products to provide speed and position control.

Also, in the photovoltaic production processes, which is similar to the well established flat panel production

schemes, HEIDENHAIN linear encoders are used from coarse resolution applications such as shuttling axes for the panels, as well as in high-end scribers outputting several hundreds of panels per hour, to deposition techniques requiring resolved constant motion. Even third generation photovoltaics that are basically printed like a newspaper use HEIDENHAIN feedback devices on the production machines.

Constantly involved in R&D, HEIDENHAIN and its family of sister companies with its leading edge technologies are proud to continue to be a part of evolving industries. Fortunately for us, our reputation of quality in the field has brought us into the energy industry and allowed us to learn a few things along the way!

For more information, go to www.heidenhain.us/el1 ■

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