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A new UHV angle encoder for high-resolution synchrotron radiation monochromators

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The high precision of 0.1 arcsec required for the positioning of optical elements in new two-axes monochromators at the undulator beamlines at BESSY II has led to the development of UHV-compatible high-precision angle encoders. Mounted directly on the rotation axes, they provide substantial advantages over measuring systems connected outside the vacuum vessel. Making use of a fast closed-loop control system, an accuracy of 0.1 arcsec at a resolution of less than 0.01 arcsec has been experimentally verified.

Keywords: angle encoders; monochromators; ultrahigh vacuums.

1. Introduction

For an optimum transformation of the high brilliance of undulator-based synchrotron radiation sources into high photon energy resolution and high photon density, beamlines have been developed for BESSY II which employ the principle of two-axes monochromators. In these monochromators, two independent rotations, one of a grating and the other of a plane mirror in front of the grating, are the only motions required for a photon energy scan of the monochromator. This makes it possible to select independently the incidence and diffraction angle at the grating which, on the other hand, can also be used to minimize the optical aberrations of the monochromator without moving any other part of the whole beamline. This is particularly useful for beamlines which are dedicated to the highest photon energy resolution over a large energy range or microscopic spot sizes. The best attainable figure accuracy of mirrors and gratings for state-of-the-art monochromators is about 0.1 arcsec. From this number we deduce an accuracy for the angular positioning of the mirrors and gratings in our monochromators of 0.1 arcsec. The corresponding angular resolution should be of the order of 0.01 arcsec. The standard positioning system used up to now consists of a stepper motor which drives a spindle through a reduction gear. The spindle is then coupled to the lever arm of an angular sine drive of the mirror or grating inside the ultra-high-vacuum vessel. The positional readout is obtained by a precision linear encoder connected to the spindle outside the monochromator vessel. The encoder is being exposed to environmental changes and is located far from the actual axis of the optical element to be controlled. In an earlier work (Senf *et al.*, 1995) we have pointed out improvements of the wavelength readout of a monochromator by making use of a high-precision incremental angle encoder connected directly to the rotation axis of an optical element. The development of such a measurement system has now been successfully carried out in a cooperative effort by the measuring system manufacturer HEIDENHAIN and by BESSY.

2. Incremental angle encoder

During the past two years a conventional high-precision angle encoder has been modified in order to make it compatible with UHV requirements and particularly with high temperatures. For this purpose certain parts have been replaced or even transferred to an interface card. Fig. 1 illustrates the principle of the incremental angle encoder. When a circular scale with a very fine line grating is moved relative to another grating with the same structure, the lines of the two graduations alternately align. The resulting light–dark modulation is sensed by four photovoltaic cells. The sinusoidal phase-shifted current signals are then amplified, digitized, *etc.* in the subsequent electronics.

Fig. 2 shows a simplified schematic cross section through the angle encoder with its integral stator-side coupling and two of the four scanning heads. The fourfold scanning of the grating contributes to its high degree of accuracy. Moreover, a special correction routine can be carried out to determine and store the correction data. The photograph in Fig. 3 presents the UHV-compatible angle encoder RON905-UHV, with its 170 mm-diameter stainless-steel shielding and electrical connector. Additional improvements in the analysis and data treatment yielded a total gain in resolution and accuracy as detailed in Table 1 and described below.

3. Results

After successful tests of a prototype, further UHV encoders have been manufactured. By now, two of them have been tested for more than six months in the first of the new BESSY II monochromators. The positioning system of the monochromators consists of a conventional drive unit, *i.e.* stepper motor, spindle and lever arm. One angle encoder has been mounted directly on the grating rotation axis and another one on the mirror rotation axis, both inside the vacuum vessel. For comparison, two precision linear encoder systems have been mounted as already described and as used with former mono-

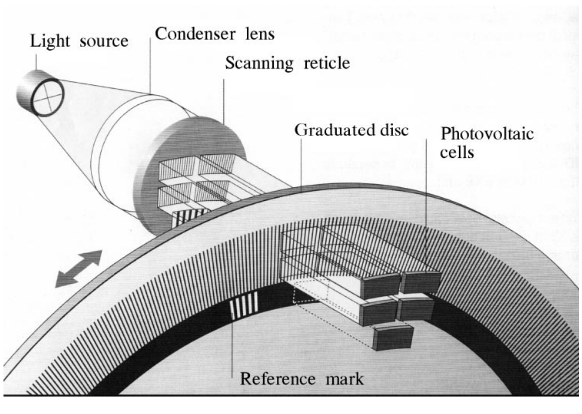

Figure 1
Principle of photoelectric scanning of radial gratings on glass.

Table 1
Angle encoder for vacuum applications with interface card.

Specification	Angle encoder RON905-UHV
Vacuum tolerance	$<10^{-9}$ mbar; 750×10^{-12} torr
Accuracy	$\pm$0.2 angular seconds (PV-value) guarantee for full 360° rotation
Operating temperature	283–303 K
Maximum bake-out temperature	383 K
Measuring step with IK320	Approximately 0.01 angular seconds; maximum resolution approximately 0.0022 angular seconds
Specification	**Interface card IK320**
Dimensions	Double-height VME board, size B
VME bus specification	ANSI/IEEE STD 1014-1987, ICE 821 and 297 double-height board with J1 t connector, 1 slot interrupter D08 (O) K ROAK
Signal interpolation	4096-fold
Adjustment of encoder signals	*Via* maximum 4096 measuring points (adjustable)

chromators. For independent positioning control an autocollimator (ELCOMAT 2000, Müller/Wedel, Germany) has been set up, realizing an autocollimation path together with the installed X-ray optics, *i.e.* plane mirror, plane grating blank and normal retro-reflecting mirror. A comparison between the readout of the angle encoder on the grating axis and that of the autocollimator is shown in Fig. 4. In order to reveal backlash, stick-slip effects *etc.*, the grating drive has been moved with highest resolution starting from its resting point. The new angle encoder unambiguously displays the expected linear relation. (0.1 arcsec at the encoder corresponds to 0.2 arcsec at the autocollimator since the autocollimator reading counts twice the actual rotation of the grating.) The observed broadening of the line is caused by the total noise of the autocollimator. The noise level of the angle encoder is about one order of magnitude lower, as can be also seen from Fig. 4. The readout of the linear encoder was recorded simultaneously and is displayed in Fig. 5. In contrast to the data of the angle encoder, the result is not an unambiguous straight line. The graph of the angle positions calculated from the readout of the linear encoder at the lever arm and of the autocollimator readout should give, at least for the small scan range, a line with the same slope as indicated in

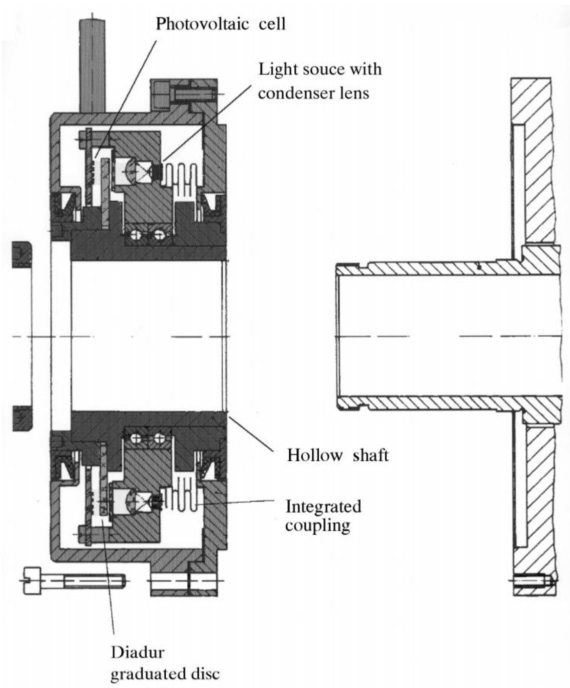

Figure 2
Simplified schematic diagram of an angle encoder with integral stator coupling and two of the four scanning heads.

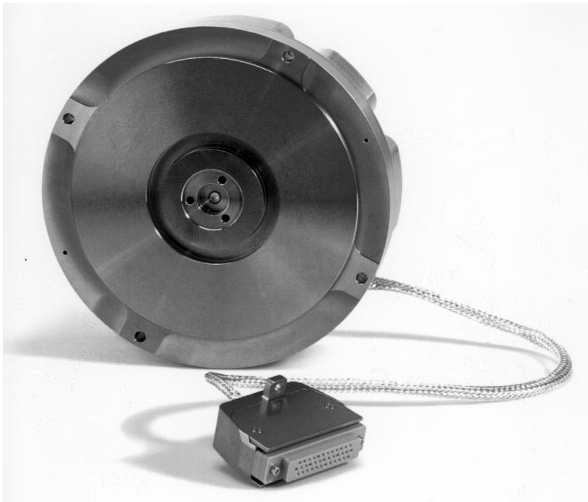

Figure 3
Photograph of the UHV-compatible angle encoder RON905-UHV.

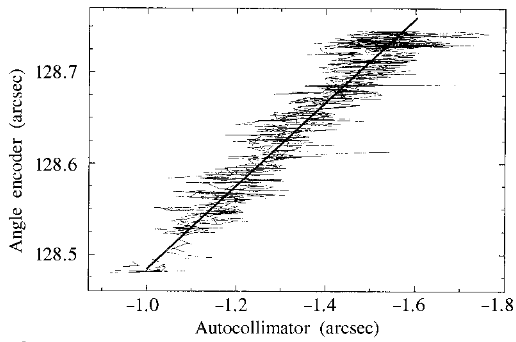

Figure 4
Comparison between the readout of the RON905-UHV on the grating axis and that of a high-precision autocollimator.

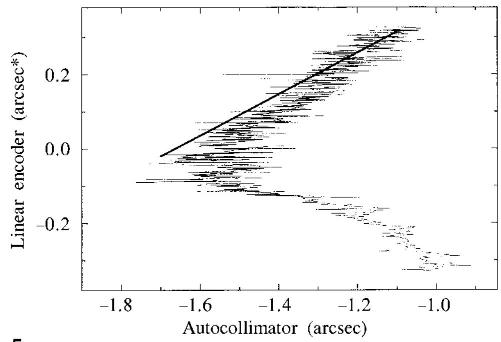

Figure 5
Comparison between the readout of the linear encoder which has been attached outside the vacuum vessel and a high-precision autocollimator. The data, calculated in arcsec* for a better comparison, were taken simultaneously to the data displayed in Fig. 4.

Figs. 4 and 5. What is observed at the start of the scan is most likely an elastic deformation of the mechanics between the two different encoders. The scan range displayed is fairly small; however, the comparison between the two curves clearly shows the advantage of the UHV angle encoder being directly mounted on the rotation axis. The measuring position of the linear encoder outside the vacuum vessel is too far away from the relevant optical elements. Because of the unambiguous and precise response of the angle encoders, a closed-loop control system between the angle encoders of the optical elements and the corresponding drive systems has been installed and successfully tested during recent months. This system allows control of the optical elements with sub-0.1 arcsec precision and 0.01 arcsec resolution. As shown, this is impossible by using the readout of linear encoders.

4. Conclusions

New UHV-compatible high-precision angle encoders have been built. By using these it has been experimentally verified that the mechanical positioning precision required for today's almost perfect plane and spherical optical elements is achievable. The new RON905-UHV encoders, which are now commercially available, are key components of our new set of high-resolution grating monochromators at the undulator beamlines of BESSY II.

References

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