UvA-DARE (Digital Academic Repository)

Adapting a high-precision angle encoder to use in ultrahigh vacuum

de Haas, E.; Barsingerhorn, W.; van der Veen, J.F.; Sturre, J.

DOI

[10.1063/1.1147867](https://doi.org/10.1063/1.1147867)

Publication date

1997

Published in

Review of Scientific Instruments

[Link to publication](#)

Citation for published version (APA):

de Haas, E., Barsingerhorn, W., van der Veen, J. F., & Sturre, J. (1997). Adapting a high-precision angle encoder to use in ultrahigh vacuum. *Review of Scientific Instruments*, 68, pp 1341. <https://doi.org/10.1063/1.1147867>

General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

Adapting a high-precision angle encoder to use in ultrahigh vacuum

E. de Haas, W. Barsingerhorn, and J. F. van der Veen^{a)}

FOM-Institute for Atomic and Molecular Physics, Kruislaan 407, 1098 SJ Amsterdam, The Netherlands

J. Sturre

Heidenhain Nederland B.V., P.O. Box 107, 3900 AC Veenendaal, The Netherlands

(Received 14 August 1996; accepted for publication 5 November 1996)

Minor modifications to a commercially available angle encoder which normally operates in air make it suitable for use in an ultrahigh-vacuum environment. Its compact design is expected to lead to a wide range of applications in surface science instrumentation. © 1997 American Institute of Physics. [S0034-6748(97)02002-9]

I. INTRODUCTION

Recently, Schief, Marsico, and Kern described a modification to a commercially available incremental angle encoder, rendering it suitable for readout of a goniometer axis in an ultrahigh-vacuum (UHV) environment.¹ In order to prevent outgassing into the vacuum, they encapsulated some components of the encoder in differentially pumped housings. Such a modification is effective but limits the encoder's range of applications. For example, it is impractical to directly couple such an encoder to the different axes of a goniometer having more than one degree of freedom. In this article we describe a simpler adaptation to the same encoder, which makes it more widely applicable. For proper functioning of the encoder in UHV it proved to be sufficient to replace a few components by ones that have a very low outgassing rate and withstand bakeout temperatures of 150 °C. The accuracy of the encoder was found to be unaffected by these changes. Our modified encoder fits onto a piezoelectrically driven rotary stage which we have developed earlier for surface science experiments.² Such stages, each provided with its own angle encoder, can easily be combined into a multiaxis goniometer.

II. PRINCIPLE OF OPERATION

The angle encoder concerned operates on the well-known principle of photoelectrically scanning a graduated glass disk with a fine radial grating of opaque lines (see Fig. 1 and Ref. 3). We briefly explain the functions of the various components. The graduated disk is rigidly attached to the rotor whose angular position is to be read out. Mounted on the stator, at close distance to the disk, is a scanning unit with four matching gratings ("index gratings") which are phase shifted with respect to one another by 90°. A collimated light beam penetrates both disk and scanning unit and the resulting sinusoidal modulations of the transmitted intensity with changing angle are recorded by four photodiodes (nos. 2, 3, 5, and 6) which are placed in line with each of the index gratings. Subtracting the 180° phase shifted signals from photodiodes 2 and 5 yields a sinusoidal signal free of background. Likewise, subtracting the signals from diodes 3 and 6 results in a background-free sinusoidal signal, which,

however, is 90° out of phase with signals 2–5. The sign of the 90° phase difference (negative or positive) indicates the sense of rotation. One additional photodiode (4) reads off a reference mark for absolute angle encoding and another diode (1) serves to set the reference signal to the appropriate level. The sinusoidal signals are digitized and interpolated in a standard fashion. These signal processing steps are performed outside the vacuum.

III. DESIGN

The encoder to be modified has been obtained from the company Dr. Johannes Heidenhain GmbH and is of the type ROD-250.³ This encoder features a glass disk of 64 mm diameter onto which 18 000 lines of chromium have been evaporated. This line density results in a signal having a quarter-period of 0.005°. After standard fivefold interpolation this yields a measuring step of 0.001°.

The modified encoder is shown in Fig. 2. From the original encoding unit we retained the graduated disk, the scanning unit with the index gratings, the condensor lens, and the miniature light bulb (2, 6, 10, and 11 in Fig. 2). These parts, made of G8/G10 glass, are UHV compatible and withstand prolonged bakeouts at 150 °C. Other parts, primarily for mounting and alignment purposes, were newly designed. Below we describe some components and their assembly onto the rotary stage in more detail.

The graduated disk and the scanning unit have been provided with a centering circle. First the disk was centered with the rotation axis of the rotary stage to within 5 μm, whereafter the disk was glued to a mounting ring (1) using a few drops of UHV-compatible glue.⁴ The mounting ring is made of titanium, which has a thermal expansion coefficient nearly equal to that of glass. The glue was hardened at 150 °C. Likewise, the scanning unit with the index gratings was glued onto a titanium holder (7). The scanning unit was centered by translating and orienting its holder using three set bolts (9) in the spring suspension shown in Fig. 2 in cross section A. The centerings were performed under a microscope. In this way, the orientation of the index grating could be made parallel to that of the disk grating to within ~0.06°. For better operation of the spring suspension, sliding strips of beryllium copper were inserted between the holder of the scanning unit and the springs and the bolts

^{a)}Present address: Van der Waals–Zeeman Laboratory, University of Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands.

FIG. 1. Schematic of angle encoding system.

(indicated as bold lines in Fig. 2). Using a metal foil as spacer we set the distance Δx between the scanning unit and the graduated disk to a value of $50\text{ }\mu\text{m}$.

As light detectors we used high-performance silicon photodiodes.⁵ The diodes were operated with zero bias voltage, in a mode wherein the load resistance is much higher than the parallel shunt resistance of the diode. It was verified that the photodiode chips could withstand a bakeout temperature of $150\text{ }^{\circ}\text{C}$ with no adverse effect on their functioning at room temperature. The photodiode chips were bonded to a Al_2O_3 substrate on which a gold pattern was deposited. Bonding to the gold was achieved by applying a tiny droplet of electrically conducting glue⁶ to one edge of the chip. The detector assembly remained fully intact after bakeout. We note that in the original standard encoder unit the photodiodes are mounted on synthetic printed circuit board, which is a strongly outgassing and nonbakeable material. Schief and co-workers found a solution to this problem by encapsulating the photodiode assembly in a differentially pumped housing;¹ but, as explained above, we found a simpler solution, namely by redesigning the mounting plate and selecting temperature-resistant photodiodes.

The holders for the miniature light bulb and the condenser were made of aluminum 51ST, which efficiently conducts away the heat produced by the light bulb. The remaining parts in the modified design were manufactured from stainless steel 304. Finally, the assembled encoder and the rotary stage onto which the encoder is mounted were subjected for a few hours to a $150\text{ }^{\circ}\text{C}$ bakeout in vacuum. This temperature is sufficient for removal of adsorbed water vapor. Degassing rates for the materials chosen are typically of the order of $\sim 10^{-10}$ – $10^{-8}\text{ Pa m}^3\text{ s}^{-1}\text{ m}^{-2}$ after bakeout. The glues used^{4,6} are epoxy resins known to have low outgassing rates below $\sim 190\text{ }^{\circ}\text{C}$ ($\sim 10^{-5}\text{ Pa m}^3\text{ s}^{-1}\text{ m}^{-2}$) and are used only in extremely small quantities. A point of concern may be the use of the light bulb, which represents an encapsulated volume containing rest gases. We kept the light bulb sealed as delivered by the supplier, but one could also replace this item by a nude tungsten filament. The assembly is suitable for use in an UHV environment having a base pressure in the range 10^{-8} – 10^{-7} Pa .

FIG. 2. Assembly drawing of angle encoder, adapted to use in ultrahigh vacuum: (1) titanium mounting ring; (2) graduated disk; (3) spring; (4) photodiodes ($6\times$); (5) Al_2O_3 substrate; (6) scanning unit with index gratings; (7) titanium holder for the scanning unit; (8) set bolts ($5\times$) for adjustment of light intensities on the diodes; (9) set bolts ($3\times$) for translation and orientation of the scanning unit; (10) condenser lens; (11) light bulb.

IV. PERFORMANCE

Prior to testing the performance of the encoder, the amplitudes and phase angles of the electrical output signals from the photodiodes were adjusted using a commercially available diagnostic measurement kit.⁷ The light intensities falling onto diodes 2, 3, 5, and 6 were adjusted to the required levels by turning each of the four set bolts (8) in or out. A fifth set bolt (8) in front of diode 1 serves to set a trigger level for the output signals. The phase angles between the four sinusoidal output signals were optimized by a slight reorientation of the index gratings using set bolts (9). Optimization resulted in a positioning error smaller than $\pm 4.5\%$ of the signal period of 0.02° , that is, $\pm 0.001^{\circ}$. On top of this error are slowly varying angle deviations associated with eccentric mounting of the disk, etc. The former error (of short period) can be reduced and the latter error (of long period) can be virtually eliminated by appropriate software operations. To this end we fed the read-out signals into the PC counter card IK121 developed by Heidenhain.

The performance test involved checking the angle reading of the encoder against the reading of a collimator. Encoder readings were taken with and without corrective software operations. The collimator measured the angular position of a light beam which was specularly reflected against a mirror mounted on the rotary stage. The mirror was

hexagonally faceted so as to cover a 360° range of angles. In the absence of corrections, the short- and long-period tracking angle errors were measured to be $\pm 0.0015^\circ$ and $\pm 0.0005^\circ$, respectively. With corrections, these errors were reduced to $\pm 0.001^\circ$ and $\pm 0.0002^\circ$. We conclude that the readout accuracy of the modified encoder is as good as that specified for the original encoder, see Ref. 3.

In surface science there is an increasing need for reliable UHV-compatible angle encoders with measuring steps in millidegree and submillidegree ranges. In Ref. 1 their usefulness was demonstrated in the area of high-resolution He-atom diffraction. Applications are also foreseen at synchrotron radiation facilities in the areas of surface x-ray diffraction⁸ and in beam-line optics, where the encoder may read out accurate diffractometer circles or goniometers placed in UHV.

ACKNOWLEDGMENTS

We thank R. S. Mastenbroek, J. ter Horst, and I. Attema for their assistance during the performance tests. This work

is part of the research program of the Foundation for Fundamental Research on Matter (FOM) and was made possible by financial support from the Netherlands Organisation for the Advancement of Research (NWO).

¹H. Schief, V. Marsico, and K. Kern, *Rev. Sci. Instrum.* **67**, 2026 (1996).

²E. de Haas, W. Barsingerhorn, and J. F. van der Veen, *Rev. Sci. Instrum.* **67**, 1930 (1996).

³Catalogue "Incremental Angle Encoders," Dr. Johannes Heidenhain GmbH, D-8225 Traunreut, Germany.

⁴Glue of type Epo-tek H61, Epox Technology, Inc., Watertown, MA 02172.

⁵Bondable silicon chip of type OSD2.5-5T, Centronic Ltd., Croydon CR9 0BG, U.K.

⁶Glue of type Epo-tek H31D, Epox Technology, Inc., Watertown, MA 02172.

⁷Encoder Diagnostic Set PWM7, Dr. Johannes Heidenhain GmbH, D-8225 Traunreut, Germany.

⁸See, e.g., R. Feidenhans'l, *Surf. Sci. Rep.* **10**, 105 (1989).