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On the Use of Electronic Tilt Sensors as Angle Encoders for Synchrotron Applications

G. S. Knapp and H. You
Materials Science Division
Argonne National Laboratory
Argonne, IL 60439

Gary R. Holzhausen
Applied Geomechanics Incorporated
Santa Cruz, CA 95062

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Abstract

We have tested several electrolytic tilt sensors produced by Applied Geomechanics Inc. A pair of sensors were tested by mounting them on the Chi circle of a Huber 4 circle diffractometer. The angles were scanned in 1° intervals over a range of ±35°. In these tests the resolution was about ±5 μrad but the repeatability depended on angle and varied from 70 μrad (one standard deviation) at large angles to 7 μrad at small angles. This type of tilt sensor may be too slow(2-10 second settling time) as a primary angle encoder for a monochromator or diffractometer, but for a system run by stepping motors, they would prove quite useful as secondary angle encoders. Other models which have a narrower angular range would be useful in setting and tuning focusing mirrors.

Introduction

The accurate measurement of angles is difficult in the hostile environment in which monochromators, mirrors and other beam line components must operate. In many cases the angle encoder must be insensitive to high radiation environments, may need to be ultrahigh vacuum compatible, should be quite sensitive and reproducible, and should have a reasonable time response. We have tested some electrolytic tilt sensors produced by Applied Geomechanics Inc. to use as angle encoders because of vacuum and radiation[1] compatibility and they are easily mountable since they do not need to be on the center of rotation. These sensors operate on the principle that a bubble, suspended in a liquid-filled case, is always bisected by the vertical gravity vector. As the case tilts, the case moves around the bubble, linearly changing the electrical resistance measured through the electrolyte. These sensors can measure deviations from the vertical direction. The wide angle sensors may be useful for angle encoders for our double crystal monochromator for the Basic Energy Sciences Synchrotron Radiation Center (BESSRC) Beamlines to be built at the Advanced Photon Source, Argonne National Laboratory. We have also tested more sensitive sensors which should be useful for aligning and focusing mirrors.

Use as an Angle Encoder for Double Crystal Monochromator

In another article[2] in these proceedings, we describe our design of the BESSRC double crystal monochromator. This monochromator uses a vacuum-compatible Huber 430 goniometer which is connected through a differentially-pumped section to the double-crystal mounts. The goniometer is in a moderate vacuum of 10^{-6} to 10^{-7} torr and the crystals will be in a vacuum of 10^{-9} to 10^{-10} torr. The Huber is to be run by a stepping motor through a 40:1 gear reducer. This combination has a resolution of 2 μrad. Reproducibility is much harder to estimate, but the Argonne double crystal monochromator at beamline X6B at National Synchrotron Light Source (NSLS) has a similar design and is reproducible to better than 10 μrad . The monochromator at NSLS does not use any type of encoder. The accuracy and reproducibility depend on the mechanical stability of its components and the assumption that the stepping motor system does not lose steps. On rare occasions, due to equipment failure, operator error, or start up after design change, angle information will be lost. In these cases, an absolute angle encoder would be very useful.

The Bragg angle ranges of the BESSRC monochromators will be 5° to 60°. The sensor we tested was a 2-axis Applied Geomechanics Inc. Model # 757 Miniature Electrolytic Tilt Sensor with an angular range of 80°. In figure one we show the principles of operation.

As the case tilts, the vial moves around the bubble, alternatively covering and uncovering the two excitation electrodes. When a constant AC voltage is applied across the two excitation electrodes, the AC output measured at the central pick-up electrode changes in linear proportion to the tilt angle. In other words, the transducer behaves as an AC variable resistor (potentiometer). To provide the AC signal and phase-sensitive readout of the response, we utilized an Applied Geomechanics Inc. Model 781 Signal Conditioning Unit. This unit produces a DC signal which we read with a computer-controlled Keithley voltmeter which has an active filter. After each move of one degree, we waited 10 seconds before reading out the signal. In figure 2 we show the outputs of both axes of the sensor as a function of angle. The responses of the sensors are almost linear.
The non-linearly we can easily calibrate out using our Huber goniometer. What is more important to test is the noise, reproducibly and response time. It is necessary to wait for the liquid to settle down its motion relative to the case, also, for low noise levels; a good deal of electronic filtering is required. We found that 10 seconds was more than adequate to measure the sensor's response after a move.

We tested resolution and repeatability by mounting the two-axis sensor on a Huber four-circle diffractometer, where the vertical angles can be changed by the Chi circle. By rotating the phi circle we aligned the x- axis of the sensor with the axis of rotation and we repeatedly scanned the sensor from -35° to 35° in steps of 1 degree. The sensor response is slightly temperature dependent, so we monitored the temperature as well as the outputs of both axes. Each scan of angle took about 30 minutes and 9 scans were performed with either the x-axis or y-axis aligned with the axis of rotation.

In order to evaluate the resolution and repeatability, we first corrected the angle data for the small temperature effect. We averaged a series of runs for each axis and then plotted the differences from the average for each run (figures 3 and 4). There are two possible sources for the sensor's repeatability errors. The manufacturer quotes a repeatability of the Huber goniometer as ±10μrad. As we see from figure 3, the repeatability of the data are considerably worse the that at large angles. Near zero the repeatable is approximately that of the goniometer. The data shown in figure 3 show the resolution is about ±5 μrad. The tilt sensors we tested were not as reproducible as the stepping motor- goniometer system in normal operation. What it does show is that such sensors will be useful as a checking device, and will be useful whenever the computer, stepping motor system gets lost for any reason. These sensors are quite inexpensive and can be mounted anywhere, so it seems useful to incorporate such sensors into any stepping-motor-driven, vertical-axis device.

Use of High Gain Tilt Sensor for Mirror Alignment and Focusing

We have also done similar tests on three high-sensitivity tilt sensors which had ranges of ±1°. For these tests we used an Applied Geomechanics Calibrated Tilt Stage Model 790. These tilt sensors were tested for repeatability over the range of ±2 mrad. In each case the repeatability was of order 10 μrad. This kind of repeatability may make it much easier to tune up a mirror both in angle and in bending radius. The ability to set the angle means that the height of the beam can be set to 0.3 mm for a 60 m long beamline (30 m after the mirror). We would also like to be able to set the focusing of the mirror. The angle difference, $\Delta\alpha$, between the ends of the mirror is approximately given by $\Delta\alpha = L\theta / l$ where L is the length of the mirror and l is the focal length of the mirror and θ is the incidence angle on the mirror. Using l as 30 m, L =1 m and θ as 5 mrad we find $\Delta\alpha$ =167 μrad. Therefore we can focus the mirror to within 6% of optimum without the need to directly measure the beam spot. This error would give a beam spot of only 60 μm for a zero-emittance undulator beam. The position of the spot can also be set to ±0.3 mm. It is clear that the use of these sensors may greatly reduce the difficulty in aligning the beamline mirrors.

Acknowledgments

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References

1. Private communication; Wilfred Schildcamp has shown how the standard type of Applied Geomechanics tilt sensors can be made UHV and radiation compatible. The standard ceramic potting compound is replaced by TorrSeal™, produced by Varian Corp. and the normal Teflon-coated wire is replaced by polyimide insulated wire.

2 Ramanathan M, Beno M. A., Knapp G. S., Jennings G., Cowan P., and Montano P. A., Rev. Sci. Instr. (These Proceedings), 1995.

Figure Captions

Figure 1 The principle of operation of the electrolytic tilt sensor

Figure 2. The response of the two axes of the tilt sensor as a function of angle.

Figure 3: The differences in the response of the x-axis of the sensor as a function of angle. By difference we mean the change in the reading of the sensor from the average of the nine runs. The numbers indicate the different runs.

Figure 4 . The differences in the response of the y-axis of the sensor as a function of angle. By difference we mean the change in the reading of the sensor from the average of the nine runs. The numbers indicate the different runs.

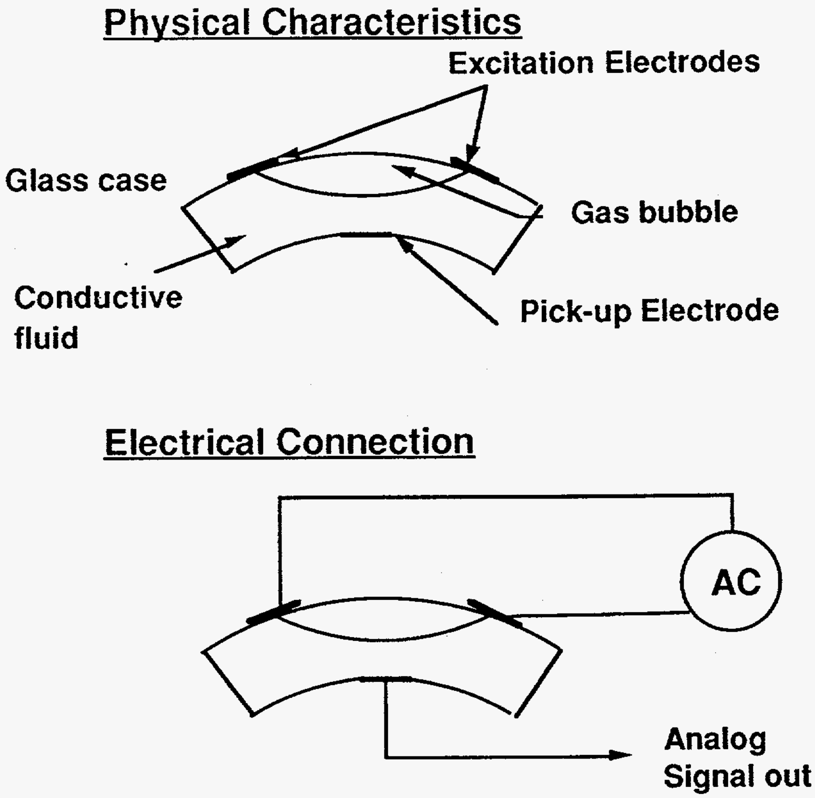

Fig.1, Knapp et al.

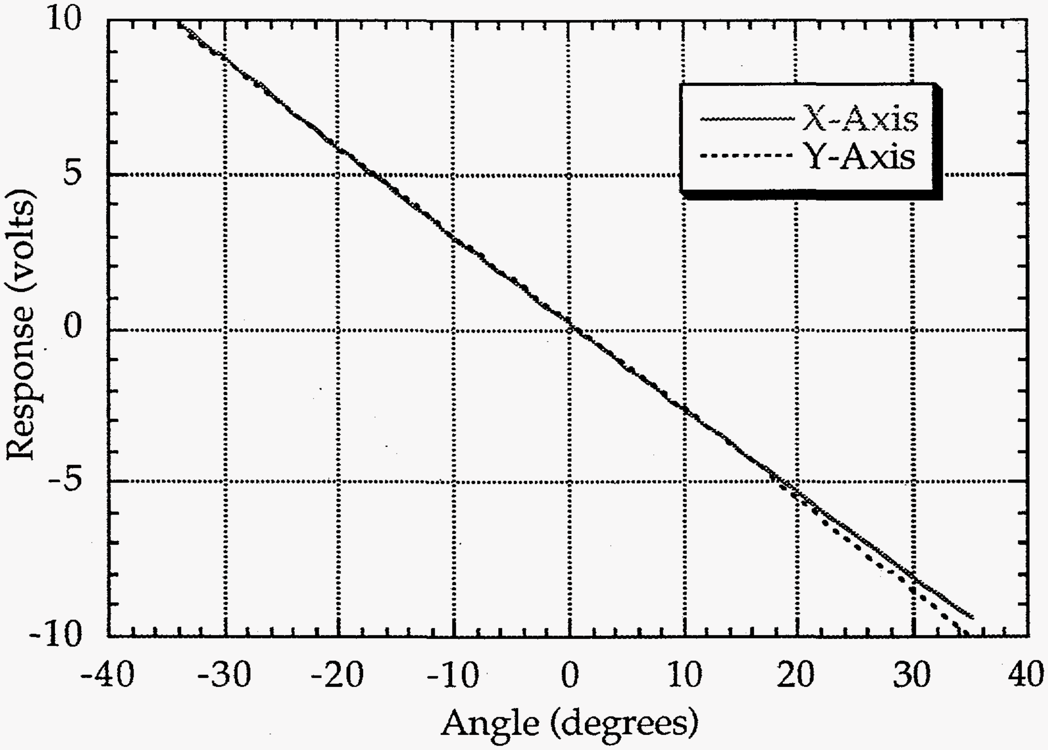

Fig.2 , Knapp et al.

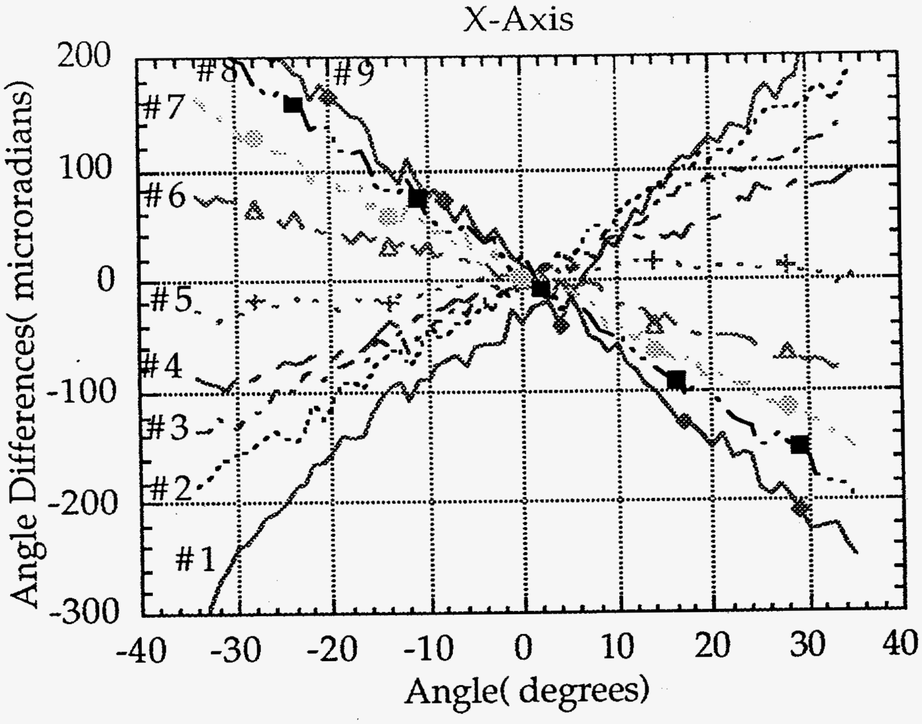

Fig.3 , Knapp et al.

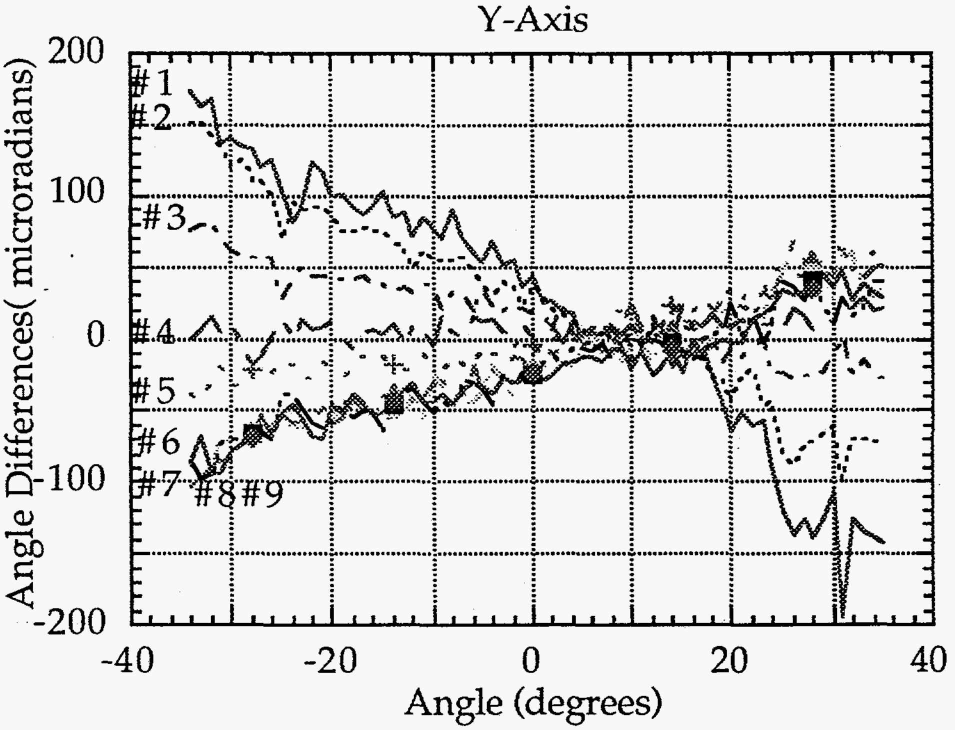

Fig.4, Knapp et al.