J. Synchrotron Rad. (1998). **5**, 829–831

An electrostrictive drive for fine pitch control in double-crystal monochromators

A. G. Shard,[a*]† V. R. Dhanak[a] and A. D. Smith[b]

[a]*IRC in Surface Science, The University of Liverpool, Liverpool L69 3BX, UK, and* [b]*CLRC Daresbury Laboratory, Warrington WA4 4AD, UK. E-mail: aqs@dl.ac.uk*

(*Received 4 August 1997; accepted 27 October 1997*)

Precise control of the pitch angle of the crystals in a double-crystal monochromator is essential to preserve their accurate alignment while the instrument is scanned. Computer-controlled piezoceramic electrostrictive actuators have recently been installed to the top crystal in two monochromators at the Daresbury SRS to facilitate this. This complements the coarser control provided by the existing stepper motor to give an accurate positioning of the crystal alignment over the full rocking-curve width of the crystals. To maintain accurate alignment during a scan, a number of servo feedback options have been devised. In this paper an analysis of the performance of these drives is presented and their utility in a variety of different experimental techniques is discussed.

Keywords: double-crystal monochromators; pitch control; electrostrictive drives.

1. Introduction

Both the Interdisciplinary Research Centre in Surface Science (IRCSS) BL4.2 at the Daresbury synchrotron radiation source (SRS) (Dhanak *et al.*, 1992; Robinson *et al.*, 1995; van der Laan & Padmore, 1990) and the Daresbury SRS BL3.4 (MacDowell *et al.*, 1988) have been described in detail. Although the layout and experimental function of the two beamlines differ considerably, they cover overlapping energy ranges and the designs of the double-crystal monochromators (Bird and Tole Ltd) used on both beamlines are essentially identical. Another similarity is that both beamlines employ a tunable first optic which removes the higher-order content of the light.

The top-crystal pitch control mechanism has been described by MacDowell *et al.* (1988) and originally consisted of a motor-micrometer for coarse adjustment and a solenoid for fine pitch control. The motormicrometer was replaced on BL3.4 with an in-vacuum stepper motor (6 arcsec step^{-1}), the operation of which, in conjunction with the solenoid and a computer-controlled servo mechanism, was described by Roper *et al.* (1992). However, the utility of the solenoid device was found to be limited due to a non-linear response and substantial hysteresis during operation. Additionally, the bulkiness of the solenoid presented weight distribution problems, particularly when the monochromator was operated over a large angular range which seriously affected beam stability.

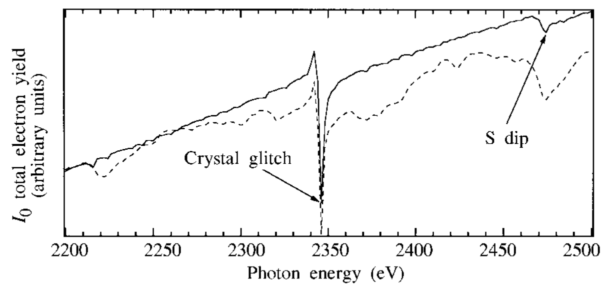
In the light of these problems, a device for fine pitch control was sought which could offer a linear and reproducible response regardless of crystal angle. To this end both monochromators were fitted with electrostrictive actuators (Queensgate Instruments, Ascot, Berkshire, UK) to replace the solenoid devices. These electrostrictive drives are operated with a 0–170 V potential giving a continuous adjustment range of 45 µm (approximately 20 arcsec) controlled by a 14-bit DAC. Owing to the almost linear response, negligible hysteresis and rigid mechanical contact of the electrostrictive actuators, a solution to the problems outlined above was anticipated. These drives have been operating on both beamlines for over two years and their reliability is proven. Computer control of the drives provides a great deal of flexibility with both the experimental technique and the rocking width of the crystal pair determining the most suitable control algorithm.

† Current address: School of Applied Sciences, The Robert Gordon University, Schoolhill, Aberdeen AB10 1FR, UK.

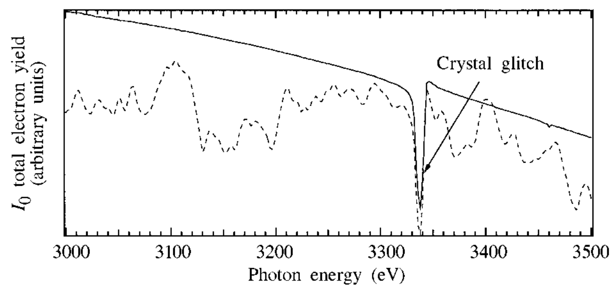
2. Beamline 4.2

In general, the top crystal is rocked by the pitch control mechanism to maximize the flux throughput of the monochromator. A subroutine for controlling the electrostrictive actuator was incorporated into our data-acquisition software; this operates by adjusting the actuator offset after every movement of the monochromator. The mode of operation consists of a relatively large 'back off' to take the top crystal to one side of the rocking curve, followed by several small 'approach' steps which continue as long as the I_0 foil drain current increases. The process typically takes 5–10 s per point which, in the case of SEXAFS and NIXSW, is small compared with the experimental data-acquisition period. This system was found to work well for both Ge(111) and InSb(111) crystals, which are commonly employed on the beamline.

Typical I_0 drain current responses are shown in Fig. 1, both with and without the electrostrictive actuator engaged. The data sets were acquired with identical data collection times using a



(*a*)



(*b*)

Figure 1
Comparison of I_0 drain current readings using Ge(111) crystals on BL4.2 with (solid line) and without (dashed line) the electrostrictive drive enabled. Energy ranges (*a*) 2200–2500 eV and (*b*) 3000–3500 eV are shown.

Ge(111) crystal pair, and normalized to provide a clear comparison. It is evident from these data that a substantial improvement in beam stability is achieved by using the actuator feedback mechanism. Only a small increase in flux is achieved, of the order of 5% at 3000 eV. It should be noted that the structure of the I_0 drain current signal without the actuator enabled consists of broad peaks and troughs; following an incomplete normalization these may result in spurious features in EXAFS data, and particularly in SEXAFS data where the signal to background can be very low. It is believed that these unwanted oscillations occur due to tiny mechanical imperfections in the monochromator mechanisms as they exhibit a certain consistency between scans, but with insufficient reproducibility to be removed by calibration.

Without the actuator, the oscillation amplitude tends to increase with photon energy. This is to be expected since the double-crystal rocking curve becomes narrower in angle at higher energies. Using the known double-crystal rocking widths and the deviations from a linear fit, the angular error in double-crystal alignment was determined to be less than $\pm$10 arcsec over the full angular range of the monochromator (15–75°), which matches the monochromator specifications (MacDowell *et al.*, 1988).

With the actuator enabled, these oscillations are eliminated at all energies. Below 2600 eV there is some random noise, which is evident in Fig. 1(*a*). This arises from the feedback system having difficulty with very broad rocking curves. The peak of the rocking curve is almost flat and the final position of the actuator is determined by random noise in the I_0 drain current reading. This problem has been solved with the use of a different algorithm which samples three widely spaced points on the rocking curve and, assuming a Gaussian profile and baseline I_0 reading of zero, calculates the position of the maximum.

Since neither routine works when crystals have an extremely small angular rocking curve, such as Si(311), another algorithm was written. This operates by scanning the electrostrictive actuator in small steps over the expected rocking peak position and moving back to the position at which the maximum I_0 reading was obtained once the scan is complete. This mode of operation increases the rocking on time by approximately 50%; however, it is not possible to use reliably the Si(311) crystals at high energies by any other method.

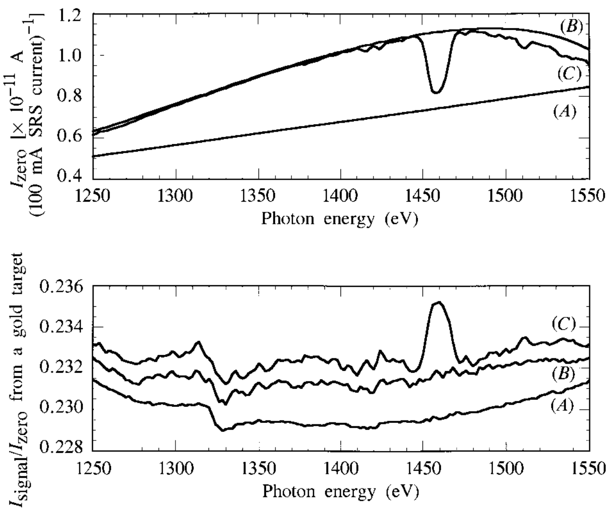


Figure 2
Comparison of intensity stability obtained from a gold target on BL3.4 for different monochromator servo options. *A* is produced by the computer driving the monochromator to produce an I_0 output intensity to match an internally determined value, *B* is by rocking onto the Bragg peak at each point, and *C* is with no servo feedback.

3. Beamline 3.4

This beamline is devoted more to bulk EXAFS measurements with higher signal-to-noise yields and therefore shorter data-acquisition times than are experienced on BL4.2. Rocking onto the Bragg peak at each point through a scan results in a dead time greater than the data-acquisition time, with the consequence that an EXAFS scan would take up to five times longer than previously. To overcome this, an alternative feedback routine has been developed.

This follows the concept of MacDowell *et al.* (1988) whereby the computer rocks the top crystal onto the Bragg peak at both the end and start energies of the requested scan range and records the measured I_0 signals. It draws a virtual line between these two points at some preset fraction of the recorded intensities, normally 80%. At each point in the scan the computer drives the electrostrictive actuator to deliver the predetermined intensity from the I_0 foils, stepping the pitch stepper also if necessary. As this adjustment is generally small, the additional dead time per point is reduced to 1 or 2 s. The resulting increase in overall scan times is generally less than 25%. The rejection ratio is used by the computer principally to ensure that SRS beam decay does not result in the available X-ray flux dropping below the level the computer is trying to servo to. This is likely to be a problem towards the end of a scan. A second major advantage is that the gradient at the top of the Bragg peak is flat; therefore, the angular variation for a specific intensity tolerance is larger than it is on the side of the peak. Alignment of the crystals is therefore maintained with a greater accuracy. Finally, it ensures that if the scan range coincides with a part of the spectral response of the beamline that is concave, or in the presence of a monochromator glitch, then the servo does not get 'stuck' searching for a predicted intensity that is higher than the maximum flux available.

The ability to collect an EXAFS scan while servoing onto either the maximum, or some preset fraction of the maximum, of the Bragg peak is also offered. In general, it is found that the signal to noise obtained by rocking onto the Bragg peak maximum at each point is not as good at that achieved using the previous feedback system. Rocking onto a preset fraction of the maximum does give comparable results; however, the time required to determine the Bragg peak maximum and then rock back off again can be considerable, giving a dead time of up to 10 to 20 s per point. This option is generally only used in beamline diagnostics to determine the position and shape of the high-energy cut-off after adjustment of the pre-mirror angle.

The typical effect of the servo on data collection is shown in Fig. 2. Scans were conducted of a solid gold target in the 1250–1550 eV range. Gold has no structure in this energy range; therefore, any unwanted structure will be easily visible. Fig. 2(*a*) gives the I_0 response with energy and, as can be seen, there is a lot of noise towards the end of the scan if the monochromator is driven without any servo feedback. This is in part due to the drift in the position of the Bragg peak with Bragg angle which remains uncorrected without servoing. The large dip at 1460 eV is unusually large and, as can be seen in Fig. 2(*b*), does not fully normalize out of the recorded spectrum. Servoing by rocking onto the Bragg peak maximum at each point in the scan gives the spectral response of the beamline. The I_0 response obtained using the I_0 intensity servo just gives the virtual line the computer is generating. The corresponding signal to noise for the three scans is shown in Fig. 2(*b*). It is clear that operating without servo feedback generates the worst noise level, with the best results being obtained from the virtual I_0 intensity system. It is thought that the residual noise seen when using the Bragg peak servo arises from slight position shifts in the output beam due to the flat top of the Bragg peak.

A third servo option for the monochromator relies on maintaining vertical beam position, as described by Roper *et al.* (1992). On BL3.4 this is of principle value in conducting ReflEXAFS measurements using the apparatus described by Smith *et al.* (1995). ReflEXAFS involves shining a vertically highly collimated X-ray beam onto a sample at grazing incidence, necessitating vertical stability of the monochromator output beam. To control this, a beam-position monitor, comprising a pair of electrically isolated copper plates separated by a 1 mm gap, is placed just before the entrance slit of the ReflEXAFS apparatus. Drain currents are measured from each of these plates (A and B) and the computer uses these values to set the monochromator pitch angle to ensure that the beam remains centred on the plates by using the relationship $(A - B)/(A + B) = 0$. Investigation of this option is ongoing; however, early trials have shown an improvement in the attainable signal to noise for ReflEXAFS scans.

4. Summary

Commercially available piezo-operated electrostricive actuators have proved to be ideal devices for finely tuning the pitch adjustment in double-crystal monochromators. They have proven reliable under vacuum conditions, their action is reproducible and the ability to control them from software offers the scope to implement different feedback methods with parameters that can be easily tuned to suit different experimental configurations.

The software routines for controlling electrostrictive actuators on BL4.2 were written by P. J. Hardman, Chemistry Department, Manchester University, UK. This work was funded by the EPSRC (BL4.2) and CLRC (BL3.4).

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