Using DCM pitch modulation and feedback to improve long term X-ray beam stability

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Abstract. In this paper we demonstrate significant improvements to the stability of the monochromatic X-ray beam intensity on several beamlines at Diamond, using a modulation of the pitch axis of the DCM with a piezoelectric actuator. The modulation is detected on an intensity diagnostic (e.g. an ion chamber) using a software lock-in technique. The detected amplitude and phase are used in a feedback to keep the DCM at the peak of the rocking curve, or any arbitrary position 'off-peak' which might be desired to detune the DCM and reject unwanted harmonics. A major advantage of this software based system is the great flexibility offered, using standard, readily available instrumentation. Measurements of the short and long-term performance of the feedback on several beamlines are presented, and the limitations of such a feedback are discussed.

1. Introduction
A critical requirement of synchrotron users is a high quality X-ray beam, maintaining a stable photon flux and rejecting unwanted photon energies. Double Crystal Monochromators (DCMs) are almost universally used in order to precisely select the required photon beam energies from either dipole or insertion device sources. It is important to maintain a constant relative angle ($\delta \theta$) between the two monochromator crystals. An unstable $\delta \theta$ results in the user seeing variations in photon energy, intensity and position.

Piezoelectric actuators are commonly used to fine tune the pitch of one or both DCM crystals. As large electric fields applied to the piezoelectric device result in only tiny changes in its size, nRadian precision adjustments can be made to the DCM crystal pitch. The use of a modulation of the DCM pitch using such piezoelectric devices in order to stabilise X-ray beam intensity has been explored for many years now [1][2][3], using lock-in amplifiers or phase sensitive detectors to maintain the two crystals in parallel. The method presented in this paper differs from previous methods in its use of software and flexible, readily available computing power to mimic the functionality of such hardware based approaches.

At Diamond we have produced a monochromator feedback system utilising a continuous modulation of the piezoelectric actuator at >100Hz. This modulation adds a small AC component to the measured intensity of the beam, as seen in Figure 2. An intensity detector with kHz bandwidth is used to observe the modulation, and the output is recorded using a standard 16bit 100kS/s ADC. A simple lock-in system, running in either Python or EPICS, is used to detect the modulation and to calculate phase data. One can use this data to maintain a constant position on the rocking curve shoulder in order to detune the DCM.
2. Description of the system

Figure 1 illustrates the system. DAC1 produces a DC setpoint, while DAC2 acts as a waveform generator with programmable amplitude and frequency. Typically, an amplitude of $<0.1\text{V}$ (on a piezoelectric actuator input range of $\pm10\text{V}$) is used. The DAC signals are added together using a 1:1 high impedance matching transformer. The AC component from DAC2 is also fed straight into ADC1 for use as a reference signal.

The modulated signal sent to the DCM causes the X-ray beam intensity to oscillate, which is recorded by a detector, such as an ion chamber, and reported back to the IOC using ADC2. It is important that the two ADCs used are synchronised to maintain a fixed phase relationship between the reference channel, ADC1, and the signal channel, ADC2.

The typical IOC setup used at Diamond uses a 5000-point EPICS waveform for DAC2, ADC1 and ADC2. The IOC multiplies the two ADC waveforms with the original sine and cosine from the waveform generator to compute the ‘IQ’ complex phase data, $C$ [4]. These are output as AO records. Mean signal strength is also calculated from the intensity monitor and output as an AO record. From this complex data, $C$, the correction to be applied to the DAC1 DC offset is calculated in order to adjust the DCM piezo and stabilise the beam intensity.

The principles behind this system are outlined below. If the initial modulation of the system

![Figure 1. Block diagram showing the function of the DCM modulation feedback.](image)

![Figure 2. Experimental data from the I11 beamline showing the effects of the modulation with an amplitude, $A_{\text{mod}}$, of 0.04V. The phase of the measured signal relative to the modulation is used to determine the direction of the feedback. The feedback can be used to either hold the peak intensity, or the shoulder position.](image)
is $\sin(\omega t)$, $I_{\text{mod}}$, from ADC1, and the detected signal is $I_{\text{signal}}$, from ADC2, then $C_{\text{mod}}$ and $C_{\text{signal}}$ are complex signals:

$$C_{\text{mod}}(t) = I_{\text{mod}}(t) \cdot e^{i\omega t}$$

$$C_{\text{signal}}(t) = I_{\text{signal}}(t) \cdot e^{i\omega t}$$

It follows that the phase difference between the modulation and the signal is:

$$\theta = \arg\left(\frac{\langle C_{\text{signal}}(t) \rangle}{\langle C_{\text{mod}}(t) \rangle}\right)$$

where $\langle C(t) \rangle$ is the time average of $C(t)$.

The sign of this phase information gives the direction in which the feedback needs to act, and the magnitude of the complex signal, $|\langle C_{\text{signal}}(t) \rangle|$, gives the size of the movement required.

3. Performance of the system

On the beamlines tested at Diamond a modulation amplitude, $A_{\text{mod}}$, of 0.04V on the DCM piezo input corresponds to angular changes of the order 100nRad to the crystal pitch. On a typical beamline the resulting change in intensity, $\delta I$, is 2% of the maximum intensity, $I_{\text{max}}$, when at the peak of the rocking curve. A modulation frequency of 111Hz is used, sufficiently high that this motion is imperceptible to the end users. Figure 2 shows experimental data, illustrating the effects of the modulation, as seen on a detector at the sample point. It can been seen that, compared to maintaining the peak intensity, holding a position on the shoulder of the rocking curve will result in an increase of the modulation effects.

Should users begin fast time-resolved experiments on the I11 beamline then the modulation may become apparent. Until such time though, the effects of the modulation are considered to
be totally negligible.

Long-term experiments show a significant improvement to the beam intensity stability over many hours. The examples presented in Figure 3 are from the I11 and B16 beamlines at Diamond. The I11 beamline uses a 22mm period in-vacuum undulator as its source, and the B16 beamline uses one of Diamond’s dipole magnets as its source. For I11 an ion chamber was used as the intensity detector, and for B16 a diode was used. This illustrates the flexibility of the system, allowing it to be easily set up to operate on a wide range of beamline configurations.

In each case, the DCM was first manually set up to provide the maximum intensity (00:00 hours). The beamline was then left for 6 hours, allowing beam to drift away from the maximum intensity. Halfway through the experiment (06:00 hours) the modulation was started and the feedback enabled. Within seconds the peak intensity is found again, automatically, and here it remains for the next 6 hours. The measured intensity shown here has been normalised to the storage ring current in order to remove the effects of top-up from the results.

4. Final remarks

Without feedback both beamlines show very different characteristics: I11 displays a sinusoidal variation with a period of hours, while B16 shows a linear drift away from the peak over time. Both drifts are thought to be ultimately due to some thermal variations of the DCM, but in both cases the modulation feedback is able to keep the detected intensity nearly constant and to greatly improve the stability of the beam intensity at the detector.

In conclusion, the feedback is able to provide improved long-term stability, and has been shown to be useful in quickly finding the peak intensity. Using this system the beam intensity can be maintained over several hours to 0.1% rms, an improvement of a factor of 5. To date, the feedback has been used at five beamlines at Diamond and has proven to be very easy to implement.

The software approach allows for implementation using hardware currently available on the beamlines. However, the limitation of a software approach compared to more traditional lock-in amplifier and integrator feedback is that the system response is a discrete, iterative procedure, dependant on the length of the EPICS waveforms. A more complex hardware solution, as described elsewhere [3], can potentially provide variation and feedback at much higher bandwidths.

Currently, the feedback has only been implemented at an update rate of 1Hz, however an increase of the feedback rate, up to 50Hz, is being investigated. This should be possible to implement without any new hardware, simply by adjusting the EPICS waveform sizes from 5000 samples, down to 100 samples whilst maintaining the previous sample rate. An EPICS implementation should be capable of performing the necessary calculations at this rate on a standard VME crate processor (a MVME5500 CPU board).

Suppression of higher frequency vibrations, greater than 5-10Hz, are beyond the scope of this software based system, and in any case, for the most part they are better reduced with hardware improvements.

References

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