Design of a Horizontally Deflecting Quadruple Crystal Monochromator (QCM) For I13 at Diamond

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Abstract:

The I13 Beamline at Diamond Light Source (DLS) is a long 230m beamline featuring two branches – Imaging & Coherence. A Quadruple Crystal Monochromator (QCM) has been designed and built by DLS for the Coherence branch.

Stability was a key requirement alongside the need to maintain the sample position in the same place for both pink and mono beam experiments.

A pseudo channel cut, horizontally deflecting, four bounce geometry was selected which provides no overall change in beam offset through the mono along with a number of other advantages.

Novel features include independent sideways motion of each Bragg axis spindle for "single spindle" operation (DCM mode) or for pink beam experiments, where the monochromator is remotely moved out of the beam. The QCM is also equipped with two sets of crystals, one set of Si(111) and one set of Si(311) crystals. To change between the two sets, the common support provides vertical height adjustment, which is implemented via a substantial motorized wedge frame design.

Although initially water cooled, the mono was also designed as a cryo cooled mono for future sub zero cooling using a silicon oil chiller or even LN2 cooling. Some key features of the mechanical design are presented along with some initial mechanical performance data.

1-Introduction

A channel cut monochromator generally offers greater stability over a typical DCM as the lattice planes of the 1^{st} and 2^{nd} crystals are intrinsically parallel. The disadvantage is that the beam offset becomes variable with energy.

A solution is to use two monolithic channel cut crystals in a four bounce geometry which provides a fixed offset (Figure 1). However it is challenging to achieve the required surface finish for the reflecting surfaces in this monolithic geometry due to the limited access to the opposing crystal surfaces for polishing.

Consequently a pseudo channel cut option was adopted where each crystal could be finished independently to a high standard and mounted individually. The 1^{st} & 4^{th} crystals are rigidly fixed, whilst the 2^{nd} & 3^{rd} crystals feature individual pitch and roll corrections via flexure pivots and coarse & fine piezo devices.

For the coherence branch, any apparent movement of the source at the sample position due to mechanical instabilities of the beamline instrumentation is less of an issue in the horizontal than in the vertical direction. Therefore we adopted a sideways deflecting geometry which also potentially offers better stability, as the crystal cage can be more directly supported from underneath.

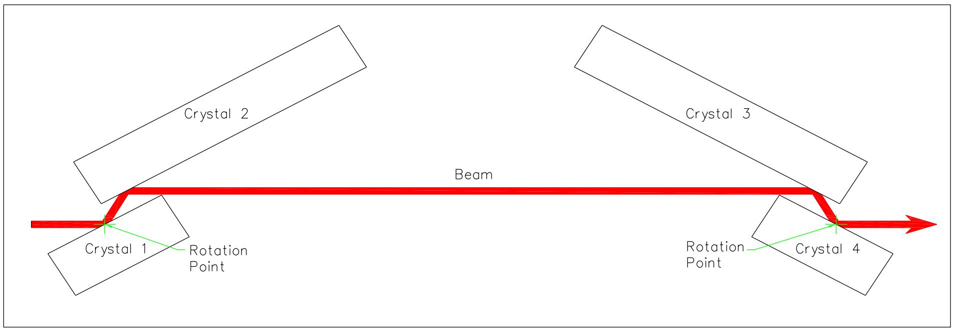

Figure 1

2-Design Objectives

The QCM was to be initially installed in the external building some 215m from the source. Here the heat load on the crystals is in the order of $<0.5W/mm^2$ and FEA showed that water cooling is adequate.

However should the QCM prove exceptionally stable in use, in order to further optimize the coherent flux, it may be moved further upstream in future to two possible locations.

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At 58m from the source the heat load is $<6W/mm^2$, where FEA showed that the effectiveness of water cooling is more marginal, although LN2 cooling would be excessive. A compromise was arrived at where we would use a silicon oil chiller running at cooling temperatures around 200°K. Consequently the monochromator had to be designed with all the typical design features of a cryo cooled mono.

A less likely but possible scenario is to situate the QCM at 30m from the source where the heat load is 23W/mm^2. Here it is probable that we would need LN2 cooling. In this case the advantage of adopting a cryo cooled design from the outset was that the QCM would be immediately ready for LN2 cooling.

The practical operating energy range of the monochromator is 6keV-23keV (approx 5°-20°) with Si(111) crystals. In addition a second set of Si(311) crystals were requested as these feature a narrower Bragg width of the rocking curve which proves advantageous for some coherent diffraction experiments.

Several solutions were considered to achieve the selection of crystal sets. An internal translation would be problematic due to the fairly rigid coupling of the through axis cooling pipes therefore it was elected to move the whole monochromator vertically.

In addition, another required feature was the ability to use either axis for single spindle "DCM" operation (in conjunction with correspondingly steering the beam with the upstream mirror to adjust for the offset change) or alternatively moving both axes completely clear of the beam for pink beam experiments whilst maintaining the same sample position. Thus each axis would also need to be independently mounted on translating supports.

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3-Bragg Rotation & Crystal Cage Mechanisms

Following previous development work carried out on high precision air bearing spindles at Daresbury Laboratory and the I20 beamline at Diamond, we elected to use the same technology for our Bragg axes.

These feature brushless DC motor driven, vertically mounted, precision air spindles with ferrofluidic seals and in-vacuum rotary encoders (shown in Figure 2) providing an effective Bragg resolution in our application, of <0.05µrad.

Figure 3 shows crystal cage 1 (crystal cage 2 is the mirror image). The 1^{st} & 4^{th} crystals are rigidly mounted with manual pre-alignment only. Similar to a previous crystal cage development carried out by DLS for the I18 beamline at Diamond, the 2^{nd} & 3^{rd} crystals are mounted using cross flexures and piezo type drives for coarse and fine adjustment of pitch & roll. Rotary encoders are mounted directly on axis for direct positional readout. Pitch and roll encoder read back resolution is <0.1µrad although much finer resolution is provided by the piezo (in the region of 10nrad under closed loop control).

The coarse range of pitch & roll motion is far in excess of what is needed (+/-5°) but minimizes set up time and provides ease of use. The fine range pitch & roll provided by the piezo is +/-240µrad.

FEA studies showed that in our case the choice between indirect bottom or side cooling the crystals was marginal regarding the thermal heat bump distortion. Consequently bottom cooling was chosen as it was deemed easier to integrate with multiple crystal sets. Both 1^{st} & 4^{th} crystals are mounted on directly cooled copper mounts via separate cooling circuits whilst the 2^{nd} & 3^{rd} crystals are cooled by braids attached to the primary cooling circuits.

For future cryo cooled use, a thermal stabilization water circuit is included with copper braid connections to key parts of the crystal cage.

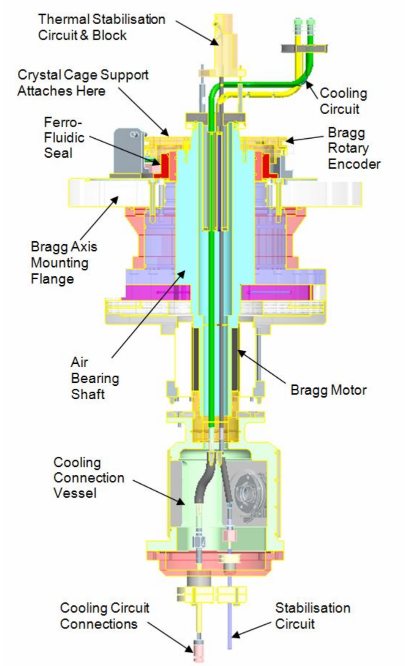

Figure 2

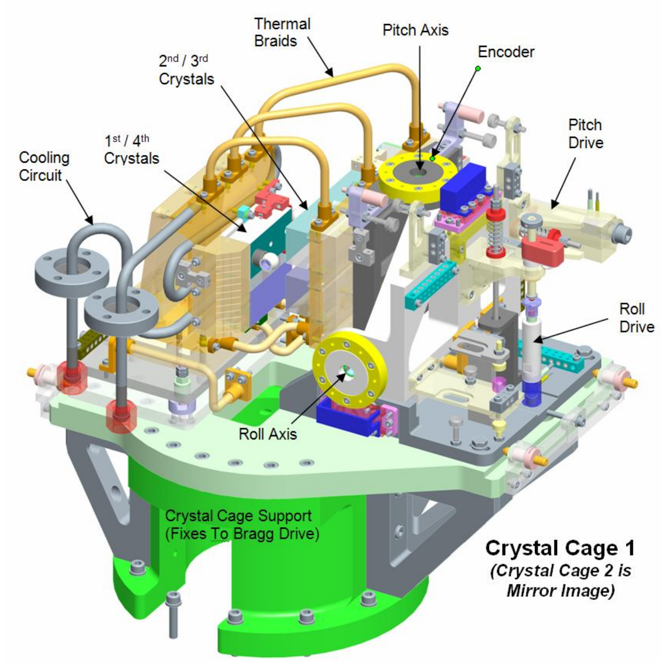

Figure 3

4-Vacuum, Cooling & Support Systems

Figure 4 shows the overall assembly of the QCM

Both spindles are housed in separate vacuum chambers joined by bellows to allow for the lateral translations. The spindle assemblies are sealed to the vessels using Viton O rings. Ferrofluidic rotary seals on the inside of the chamber provide the vacuum seal and allow the rotation of the shaft.

The "top hat" design of the chambers provides good access to the crystal cages. Each chamber is fitted with a 300l/s ion pump and a Ti sublimation pump. Achieved operating vacuum level so far is around $5x10^{-8}$mbar.

Cooling connections between the cooling and stabilization circuits are made in a separate vacuum vessel at the end of the shafts (needed for cryogenic use).

Several possible solutions to achieve the vertical translation between crystal sets were considered. We opted for a translating wedge arrangement whereby the whole monochromator is moved vertically.

Ideally we would have used granite for all of the support system, however available space around the QCM in the beamline was extremely limited together with the need for large apertures through the structure for the passage of cooling lines and to allow for the translations. Consequently we adopted an extremely stiff fabricated steel box section structure (sand filled). The lower wedge translates +/-90mm to achieve a +/25mm vertical lift.

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Both main spindle assemblies also translate +/- 8mm across the beam to allow for single spindle use or for the clear passage of pink beam.

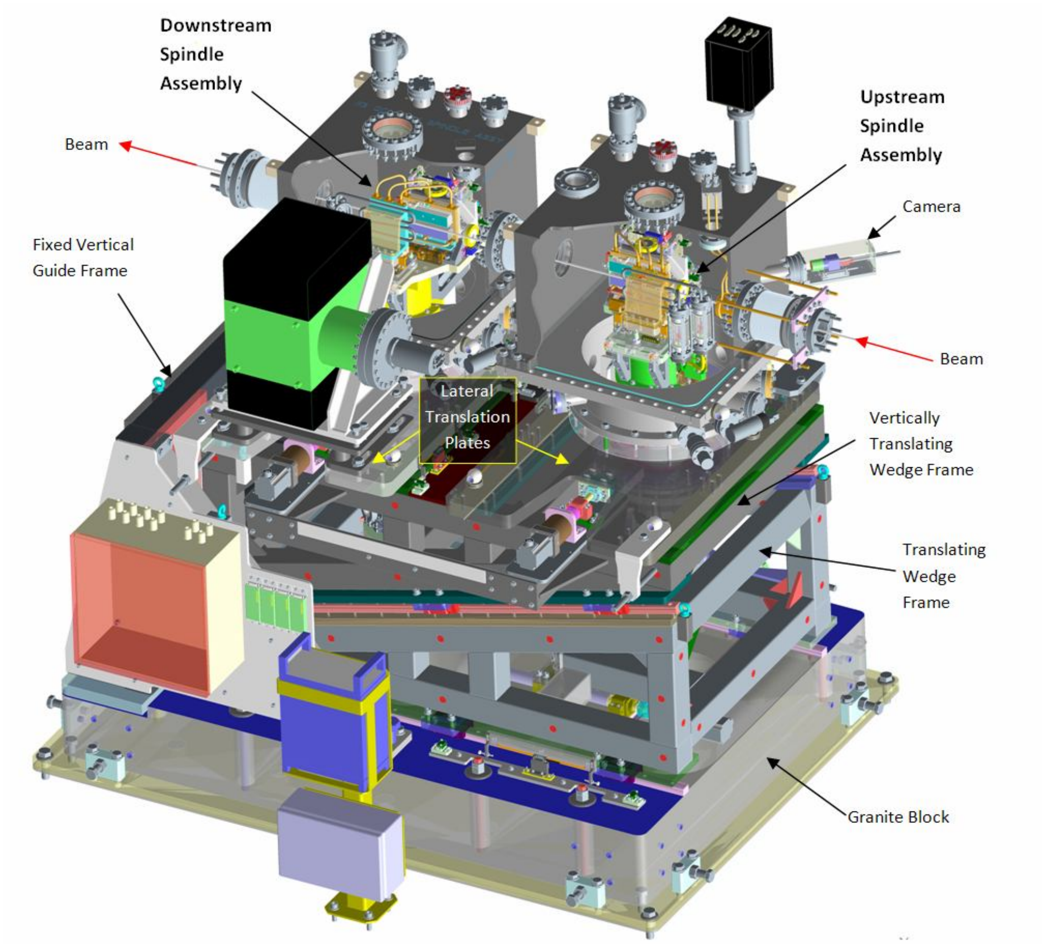


Figure 4

5-Mechanical Performance Data

The QCM has been in operation on the Coherence beamline since March 2012 during a very busy period of installation & commissioning of both branches.

Stability has yet to be quantified but is expected to be at least as good as the <0.1μrad rms stability achieved with the successful I18 crystal cage upgrade at Diamond. Motion tests made during build and commissioning point to similar performance as this design and subsequent monochromators developed at Diamond for the I09 & I23 Beamlines.

Figure 5 contains a brief summary of key mechanical test data measured using a high precision autocollimator with the QCM assembly in the installed location. Note: These were made with the system under closed loop control, although at that stage it was not fully tuned and optimized. The results also exhibit some drift as there were no temperature control measures in place.

More comprehensive data with beam is expected over the coming months as the beamline is optimised further.

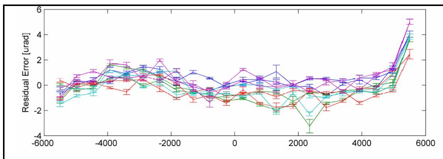
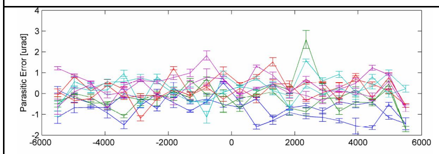
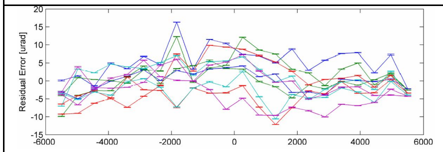
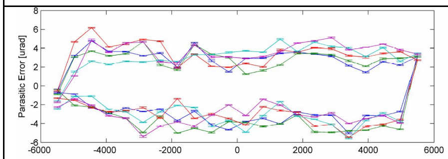
	**2^{nd} Bragg Axis Repeatability:-** Closed loop repeatability within 1-2µrad under closed loop control over +/-6mrad scans
	**2^{nd} Bragg Axis Parasitic Roll Error:-** Parasitic roll effect within 2µrad over +/-6mrad Bragg scans. Not measurable over +/-30µrad scans.
	**2^{nd} Crystal Pitch Repeatability** Around 10µrad hysteresis apparent over bi-directional +/-6mrad coarse scans. Uni directional coarse repeatability within 5 µrad.
	**2^{nd} Crystal Pitch Parasitic Roll Error** Parasitic roll within 10µrad over +/-6mrad coarse pitch scans Not measurable over +/-30µrad fine pitch (piezo) scans

Figure 5

6-Summary

A 4 bounce monochromator has been designed, built and installed at Diamond Light Source offering a flexible solution for the I13 beamline at Diamond allowing 4 bounce (QCM mode), 2 bounce (DCM mode) and pink beam experiments whilst maintaining the same sample position.

Although the specification called for a complex design which presented some significant challenges, the fundamental mechanisms employed are well proven technologies already developed and in use at DLS which should result in a reliable and stable monochromator.

Initial performance is promising and further performance data with beam is awaited as the beamline is further characterized and optimized.

References

[1] Duller G and Kay J 2008 A High Precision, High Stability, Four Bounce Monochromator for Diamond Beamline I20, MEDSI Conf. Proc.

[2] Peach A and Mosselmans F 2010, Double Crystal Monochromator Developments at Diamond, MEDSI Conf. Proc.

[3] Kelly J, Lee T, Alcock S, Patel H, Design Build & Test of a DCM for Beamlines I09 & I23 at Diamond Light Source, 2012 SRI Conf. Proc.