Beamline Design and Instrumentation for the Imaging and Coherence Beamline I13L at the Diamond Light Source

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Abstract. I13L is a 250 m long hard x-ray beamline (6 keV to 35 keV) at the Diamond Light Source. The beamline comprises of two independent experimental endstations: one for imaging in direct space using x-ray microscopy and one for imaging in reciprocal space using coherent diffraction based imaging techniques. In this paper we will discuss the fundamental design concepts of the beamline and explain their implications for the civil engineering of the endstation building and the beamline instrumentation. For the latter this paper will focus on the beamline mirror systems and monochromators.

1. Introduction and Beamline Layout

The layout of the beamline is shown in Figure 1. It is split into two branches, one for conventional imaging techniques like x-ray microscopy and one branch for lens-less coherent imaging techniques like ptychography [1]. To enable independent operation of the two branches, the electron-beam properties in the long straight section was changed to a so called double-mini-beta scheme, where additional magnets in the centre divide the straight into two subsections, where the vertical beta-function has a minimum. This allows the installation of two small gap undulators so that a high photon-flux can be achieved even at energies beyond 10 KeV. Additional canting magnets separate the direction of the photon-beam. Another feature of the double-mini beta scheme as implemented at Diamond is an astigmatic electron-beam profile, where the horizontal minimum of the beta function is located inside the frontend, thus generating a virtual horizontal photon source, whose size - and thus via the Zernike van Cittert Theorem the horizontal coherence length – can be adjusted with a set of slits. Additional CRLs within the frontend-section of the beamline will give further flexibility in adjusting the photon-beam properties to the user experiment. The separation between the two beams is further increased by using two horizontally deflecting mirrors. These mirrors serve another important purpose by separating the photon-beam from the gasbremssstrahlung. For defining the photon-beam, slit systems are located directly in front of the mirror systems and approximately 30m further downstream. The latter can be used to define the source size of a secondary intermediate source. All
these components are situated on the experimental hall floor inside the main synchrotron building. After propagating over a distance of 150 m, the beam arrives at the external building, where a set of slits determines the beam size impinging onto the water-cooled monochromators. Water-cooling is only possible due to the large distance from the source, which leads to a sufficient reduction in heatload-density.

Figure 1. Layout of the imaging and coherence beamline at the Diamond Light Source [2] and the design concept for the experimental endstation

2. The Fundamental Design Concept for the I13 Beamline

Most obviously the perpetuation of coherent flux at the coherence branch leads to very stringent specifications for the laboratory buildings and beamline instrumentation, though similar requirements apply to the imaging branch for slightly different reasons. These key specifications can be summarised as follows:

- **Minimise the impact of internal and external vibrations**, which will lead to an increased apparent source size or in other words, blow up the phase-space of the photon-beam and thus reduce the brilliance [3], which means a loss of coherent flux. In the case of the imaging branch the loss in brilliance is less important, but any vibration, will lead to a time dependent variations of the flat-field und thus make flat-field corrections very difficult or even impossible in the case of fast imaging.

- **Minimise temperature fluctuations and degrees of freedom**, which can lead to drifts. Though they are of minor importance for very fast imaging experiments, most experiments will last from several minutes up to several hours, like tomography, ptychography and fluorescence imaging. Considering that most of these experiments try to achieve a resolution well below 1 µm even temperature variation by 1/10th of a degree can lead to a blurred or distorted image. In addition, degrees of freedom can also amplify vibrations or may be their root cause.

To achieve these design goals a holistic approach of the beamline design is required. This approach must consider the beamline instrumentation, the endstation, the hutches and even the surrounding building and the building ground.

2. Laboratory Building and Civil Engineering

Due to the ground geology at the site of the Diamond Light Source, the storage ring and experimental hall are build on pillars which are anchored in the bedrock approximately 14 m below the surface. To prevent the ground-hive from deforming the floor of the facility, the floor was constructed in such a way that there is a void between the ground and the concrete floor. To minimise the movement between the ring and the external endstation building of I13 the same design concept was used for this building. The hutch floor is considered to be part of the endstation and is therefore completely isolated from the rest of the building via vibration isolation gaps (see Figure 2) to minimise the injection of
vibrations from the surrounding laboratory building into this floor and thus into the beamline instrumentation. For the same reasons the concrete walls of the hutches are neither directly connected to the endstation floor nor to the floor of the laboratory building and are considered to be an additional vibration barrier for solid- and air-born sound waves. To prevent the injection of vibrations via services like cooling water all pipes have a flexible hose at the transition point from the surrounding building to the wall of the hutch. This concept is also followed through for all air-conditioning units and active electrical components, which are supported by the structure of the external building, e.g. by hanging them from the roof. To achieve high temperature stability inside the experimental hutches, the main building will be temperature stabilised to approximately 0.5 °C whilst 0.05 °C are envisaged for the interior of the hutches. Furthermore during normal operation the hutches will be accessed via small vestibules to minimise the thermal impact of people entering and leaving the endstation and to increase the cleanliness inside.

2. Beamline instrumentation

![Figure 2. Model of the coherence mirror and deformation due to cooling water temperature](image)

Most beamline instrumentation can be divided into three major components: The main component itself, e.g. a mirror or monochromator crystal, the support structure for this component and the vacuum vessel. For the latter we prefer a top hat design, providing free access to the main components of the instrument after removing the lid, which simplifies the alignment and testing of the instrument considerably. To minimise the impact of vacuum forces and the transmission of vibrations from the vessel to the instrument itself, the supporting structure is completely decoupled from the vacuum vessel via flexible bellow and short ridged posts, which reach through the base-plate from the outside into the vacuum vessel. To minimise thermal expansion, instabilities and vibration of the support structure, this structure has a large mass and low thermal expansion constant. Therefore we often use a large granite block as the base of the instrument. This block is bolted onto a metal base-plate, which itself is grouted onto the experimental hutch floor. The number of motions is limited to the bare minimum and designed for rigidity. Where vertical motion is required we favour an over-constrained wedge design over the more traditional jack design. The pitch angle adjustment for our mirror systems is implemented via a large in-vacuum flexure stage (Figure 2), whilst the main Bragg angle adjustment for the quadruple crystal monochromator (QCM) is implemented via a stiff ex-vacuum air-bearing rotation and ferro-fluidic seals. The main instrument component is mounted onto this support system. It is important to note that in the case of beamline optics, we consider the optical element, its mounting and cooling system as one integral part, which is mounted onto a very rigid ‘optics table’; the latter interfaces to the support system. The complete optical system, including the optics table is tested and aligned at the DLS metrology lab before installation at the beamline. The importance of this can be
seen in Figure 2 (right hand side), which shows the deformation of the mirror, due to the temperature of the cooling water.

As a monochromator for the imaging branch we use a standard two bounce monochromator in vertical deflection geometry, whilst for the coherence branch we use a horizontally deflecting four-bounce design as shown in Figure 1. The crystal cage holding the first pair of crystals is shown on the left hand side of Figure 3. The design allows using Si111 and Si311 crystals as well. Only the first crystal is directly water cooled, whilst the second crystal is only thermally stabilised via braiding. As the alignment is between the two crystals within a pair is most sensitive, they are assembled into a compact and stable crystal cage, which sits on the main Bragg rotation axis. The second crystal is equipped with a fine-pitch and roll adjustment. All these motions are fully encoded so that they are reproducible. The right hand side of Figure 3 shows the undulator tuning curve, which has been used to align and calibrate the first crystal pair. The calibration and alignment of the second pair was performed relative to the first pair.

![Figure 3. First crystal pair of the quadruple crystal monochromator (QCM) and its tuning curve](image)

**5. Summary**

In this paper we discussed the main design concept for the I13 beamline and demonstrated how they impacted onto the design of the building and onto the actual beamline equipment. We briefly described to major beamline components: the large beamline mirror systems and the monochromator design. The beamline is now operational and further characterisation and optimisation is ongoing.

**5. Acknowledgement**

We acknowledge the support of the DLS Technical Department, in particular K. Collins and A. Peach. We’d like to thank the DLS optics group for access to their metrology equipment, namely S. Alcock, G. Ludbrook and H. Patel. We also acknowledge FMB Oxford, in particular J. Wiatryzk and S. Mowat, for their collaborative approach towards the mirror design. We’d like to thank I. Robinson for scientific discussions.

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