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AN IMPROVED POLARISATION ANALYSER FOR THE I16 BEAMLINE AT DIAMOND

M. Burt, S. P. Collins, S. Green, I. Horswell, J. Li, G. Nisbet, R. Pocock, J. Spiers, K. Wilkinson
Diamond Light Source Ltd., Harwell Science and Innovation Campus, OX11 0DE, UK

Abstract

The project to upgrade the I16 polarisation analyser was necessary to increase its functionality and to introduce a more robust and reliable construction. The requirement that the device was to be mounted on the arm of a diffractometer meant the construction needed to be as lightweight and as compact as possible. This provided opportunities to explore new collaborative ways of working with both in-house and external suppliers.

The paper describes the approach taken to develop lightweight aluminium vacuum chambers using a company specialising in additive layer manufacturing techniques. In addition, the design of lightweight and compact slit assemblies are detailed; these were developed in collaboration with a supplier of driven linear stages.

The paper also describes the process of using additive layer manufacturing to model prototypes to optimise the design of cable management systems where previously basing the design on 3d CAD models had proved unsatisfactory.

Another novel requirement for this device is having an x-ray detector mounted on a rotation axis in vacuum. The results of working with the in-house detector group to develop a design to allow this to be realised with all the necessary thermal and electrical connections, are outlined.

POLARIZATION ANALYSER

Overview

The I16 beamline at Diamond is dedicated to the study of advanced materials using X-ray diffraction; part of this process is to use a device that can analyse magnetic scattering from samples. Magnetic scattering is different to, and weaker than, normal scattering and analysis of the polarisation of this scattering can be used to gain insights into the magnetic properties of materials. This information allows details of the three-dimensional magnetic structure of the sample material to be determined.

The device in question, known as a polarisation analyser (PA), allows a crystal/detector assembly to be rotated about the axis of the x-ray beam direction in a similar way to a polaroid polarizer being rotated in visible light. In addition, utilizing a high quality crystal with the analyser can give higher resolution diffraction that allows structures to be studied on length scales that range from the atomic to 10^{-3}m.

The design of the PA essentially comprises an assembly of vacuum chambers, sets of slits to remove unwanted scattering, and various detectors which are arranged to rotate about different axes. Data collected from the detectors as they are moved and rotated allow information on the polarisation of the scattering to be built up.

The project to upgrade the design of the existing polarisation analyser was an opportunity to increase its functionality and to introduce a more robust construction.

The analyser itself is mounted on the arm of a diffractometer so it was important that the construction was made to be lightweight (see Fig. 1). A lightweight construction would avoid the need for additional counterweights on the diffractometer which would reduce its performance.

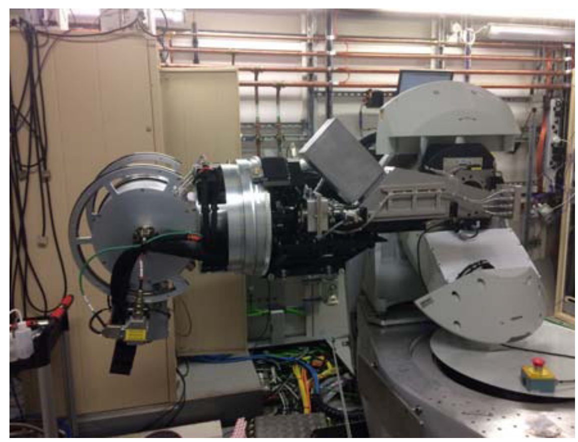

Figure 1: View of polarisation analyser mounted on diffractometer arm.

Lightweight Vacuum Vessels

A significant proportion of the structure of the PA comprises vacuum chambers. Conventionally these vessels had been constructed as two separate parts, a vessel body with a lid. In order to make an effective seal both parts have to be thick enough to accommodate an O-ring seal and also to be stiff enough to compress the seal. In addition, to compress the seal a large number of nuts and bolts are required, all of which add weight.

It was decided that by using additive layer manufacturing these vessels could be made as one piece. This would remove the need for flanges and the nuts and bolts; also the wall thickness of the vessels could be reduced to the minimum required to provide an air-tight and rigid shell.

Working in collaboration with a specialist additive layer manufacturing company: 3d-Alchemy [1], who advised on materials and minimum thicknesses to prevent porosity, the chambers were manufactured and the relevant sealing surfaces were machined to complete the finished chambers (see Fig. 2).

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Figure 2: Two of the vacuum chambers produced by additive layer manufacture of aluminium alloy. Chambers shown are approximately 600mm long by 200mm high.

Slit Assemblies

The requirement for weight reduction extended to the slit assemblies of which there are two sets: one in air and one in vacuum. In order to keep the assemblies simple and lightweight and to minimise the complexity of installation and commissioning, a collaboration was entered into with the supplier of suitable piezo-actuated linear stages: SmarAct GmbH [2].

DLS established the design of the assemblies and free issued the main components to SmarAct who assembled the linear stages to the bases and then were able to supply the slits sub-assemblies completely wired and tested. The only additional task was to add the tungsten blades.

The in-vacuum slits are in the form of two sub-assemblies each comprising a pair of slits mounted in a casing wired to connectors. The casings are then bolted together with one orientated at 90 degrees relative to the other to form horizontal and vertical slits.

The in-air slits comprised an assembly where all four actuators with their respective blades are mounted on a single plate and wired to their respective electrical connectors, which are also contained on the same sub-assembly.

In this way for both slits assemblies, a compact and lightweight design could be realised, which could be easily incorporated into the bigger assembly (see Fig. 3).

Figure 3: An example of a compact in-air slits assembly designed in collaboration with SmarAct GmbH. Stages shown have ranges of 12mm and 20mm with sub-micron resolution.

Cable Management

The mechanism of cable management was an important consideration in the design of the analyser because the detectors are rotated about an axis that is itself mounted on a second rotary axis arranged perpendicular to the first. The wiring and detector cooling lines have to accommodate the rotations in order that they can operate over the lifetime of the analyser without the cables or hoses being subject to excessive strain or abrasion that could result in damage.

Formerly, cable management has been treated as a secondary element in the design of systems however, because of the complex combination of motions on the analyser, a different approach was needed. Previously cable management mechanisms had been designed by looking at the three-dimensional model and predicting the behaviour of cables as the various axes are operated. This has proved to be unsatisfactory in the past as making predictions about the behaviour of cables of different stiffnesses in different orientations has proved very difficult.

Access to in-house additive layer manufacturing technology means that proposed designs could be produced quickly in plastic material. The design could then be assessed using suitable lengths of the actual cables that would be used on the final design. Once a design had proved to perform satisfactorily in a full-scale prototype version then this design was carried forward to be incorporated in the final design (see Fig. 4).

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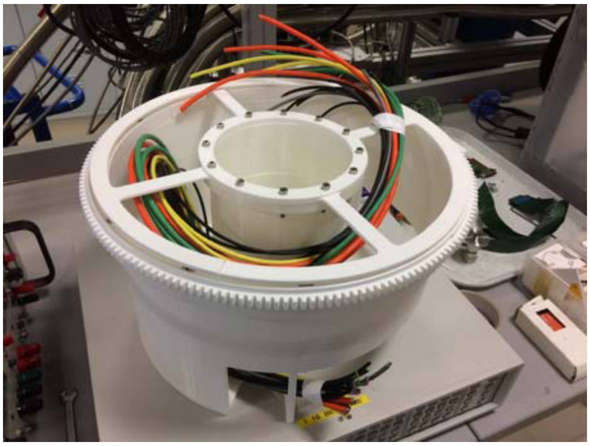

Figure 4: Image showing a prototype of the cable management mechanism produced to evaluate its effectiveness.

In-vacuum Detector

An important feature of the upgraded analyser was the facility of having an in-vacuum detector, which could also be rotated about an axis within the main vacuum chamber. The detector was adapted from a Medipix [3] Merlin detector. The Medipix detectors are produced by an international consortium of which Diamond is a member.

The requirement of putting the detector into vacuum meant all the necessary wiring to the detector had to pass though the vacuum boundary and also the detector had to be thermally managed which necessitated a thermal connection passing through the vacuum boundary. The thermal connections were designed to remove a heat load of approximately 5W and limit the temperature of the detector to below 40°C. Both the electrical and thermal connections had to accommodate the rotary motion that was required of the detector.

The electrical connections were produced in collaboration with the detector group and consisted of two custom-made ribbon connectors made of DuPont AP8535R, a polyimide material. The ribbon connectors each needed to carry 78 tracks, be flexible enough to accommodate the rotational motion of the detector and be suitable to operate in a vacuum environment. One end of each connector attached to the detector and the other was potted into the feedthrough that made a vacuum tight seal with the main vacuum chamber.

The thermal management was necessary as in operation the detector generates heat which in a vacuum environment has to be removed by conduction. The method of conduction needs to accommodate the rotary motion of the detector. To achieve this the detector board with its heatsink is mounted on a copper bracket which is attached by flexible copper braids to a pillar that is situated at the centre of rotation.

The central pillar was also produced using additive layer manufacturing as it could then be manufactured as one piece incorporating the cooling channels without the need for forming joints suitable for vacuum. Again working in collaboration with 3d-Alchemy a suitable material was chosen, this was a copper alloy which had the necessary thermal properties and, with a minimal thickness, was free from porosity.

The rotary motion of the detector is achieved by a worm and wheel mechanism, which with preloading will minimise backlash (see Fig. 5).

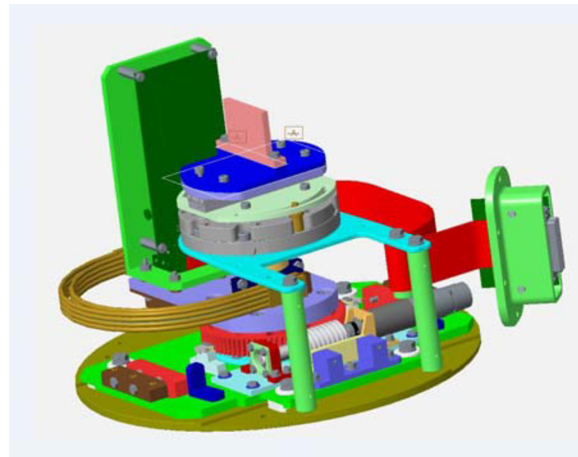

Figure 5: CAD model of the mechanism located inside the main vacuum chamber showing the detector mounted on its rotary stage with thermal and electrical connections. The face of the detector is approximately at a 100mm radius from its axis of rotation.

CONCLUSION

It is necessary to continually upgrade beamline facilities to keep them at the forefront of scientific research. In the case of the I16 beamline at Diamond, there was the requirement to improve the polarisation analyser. This provided an opportunity to work collaboratively with suppliers in ways to effectively use more advanced techniques to achieve lightweight and compact sub-assemblies.

Currently, the upgraded analyser has been installed, commissioned and is operational on the beamline. Further upgrades are planned to be carried out to improve its performance.

REFERENCES

[1] 3d-Alchemy, https://www.3d-alchemy.co.uk
[2] SmarAct GmbH, http://www.smaract.com
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