DIAMOND MULTI-BEND ACHROMATS FOR LOW EMITTANCE AND NEW INSERTION DEVICES

J. Kay†, N. P. Hammond, Diamond Light Source, Didcot, OX11 0DE, UK

Abstract

Diamond Light Source is pioneering the move to a Multi Bend Achromat storage ring lattice for low emittance combined with the creation of new straight sections available for Insertion Devices (ID). Diamond is at an advanced stage of replacing one Double Bend Achromat (DBA) cell of the existing storage ring with a Double Double Bend Achromat (DDBA). The DDBA cell which is to be installed in Autumn 2016 has 4 dipoles and has been designed with a new straight section in the middle. This allows ID radiation to shine down an existing Bending Magnet port in the shield wall for a new micro-focus protein crystallography beamline called VMX-m. This same principle will be applied to the proposed Diamond II project which will be based on a Double Triple Bend Achromat with 6 dipoles per cell achieving even lower emittance whilst providing many more IDs. This paper describes the engineering challenges of these projects.

INTRODUCTION

The move to replace a DBA cell with a DDBA cell is at an advanced stage with 2 girders measuring 7.5 m long nearing completion for installation in an 8 week shutdown between Oct 7th and Dec 5th 2016. The overall geometry is shown in Fig. 1. and a completed girder in Fig. 2. The engineering design was described more fully in [1, 2].

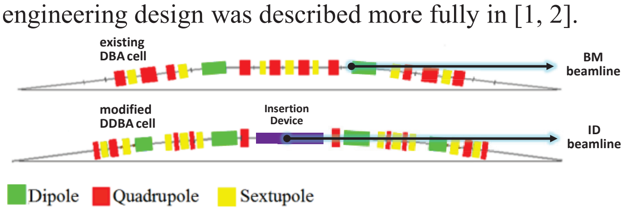

Figure 1: Schematic diagram of the existing DBA and the modified DDBA cell.

Figure 2: Completed Girder 1 in the assembly room.

† jim.kay@diamond.ac.uk

This paper will give some of the lessons learned from our experience building the DDBA cell as well as point towards a future Diamond II low emittance storage ring.

MAGNETS

A number of issues arose with the magnets to inform future projects. It is essential to keep water connections sufficiently clear of coils and coil terminations to enable pipework and cable connections to be made with good access for hands and tools (see Fig. 3.). Simply identifying 'stay clear' zones in the magnet reference design did not prove sufficient. Another issue on the sextupole magnets which have many terminal connections was the need to space out adjacent terminal blocks to give clear access for different cables to enter the terminal blocks cleanly. Although an overall length for each magnet was specified including coil overhang, the difficulties of achieving the right number of ampere-turns with a real, hollow cross-section conductor meant that this was exceeded which had implications for fitting adjacent components. It is clear that for any significant procurement contract, regular visits are essential to make sure these technical details, overall quality as well as delivery schedule issues are managed. Problems identified during final assembly are just too late and inevitably leave no time for the supplier to put things right and so the client has to compromise.

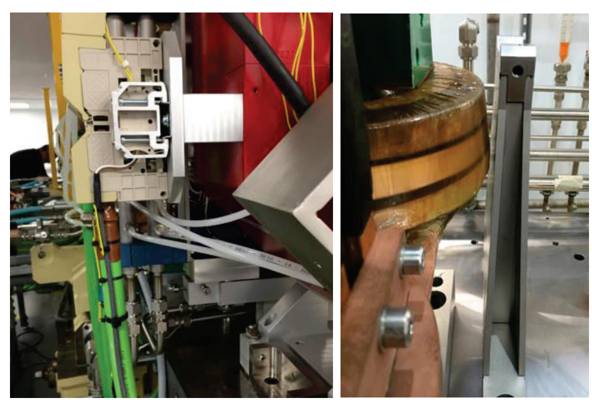

Figure 3: Magnet terminal spacer block added to separate pipes and cables and Dipole coil overhang allowance exceeded.

For more precise alignment of magnets the stretched wire technique was used [3]. This took much longer than was originally estimated by a factor 4 which had a significant impact on programme. The magnets were measured at the manufacturer using the same stretched wire bench and one shim adjustment made per magnet. However this was not checked and in the end all magnets were re-centred and shimmed at Diamond up to 3 times each.

The magnets had to be aligned in groups (see Fig. 4.) which required towers supporting the stretched wire to be re-positioned and aligned for each group. As well as taking more time for the magnet team, this process took a lot of effort for the survey team which had an impact on other alignment tasks in the programme.

Figure 4: Stretched wire measurement of magnet groups.

Because 2 dipoles are mounted on each girder there are 3 intersecting straight line electron trajectories. Figure 5 shows a system of fixed geometry, precision machined 12 mm dowel and fixing holes accurate to 20 µm for magnet and vacuum vessel fixing with a system of shims for fine magnet alignment. This process has worked well.

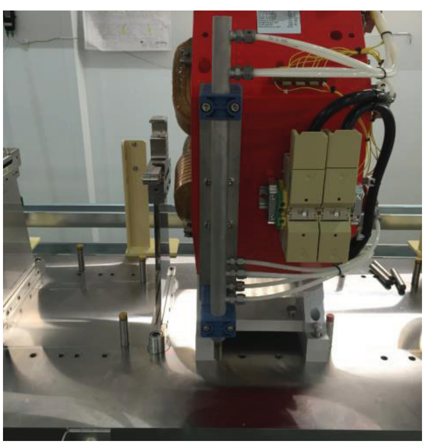

Figure 5: Dowels and shims to position equipment.

VACUUM

Helicoflex© spring reinforced metal seals are used on vacuum vessel joints close to the electron beam to ensure face to face joints with no gaps that might cause RF heating. A problem arose in the DF40 size that a reliable leak tight joint was difficult to achieve. Analysis [4] predicted that during compression of the seal the contact pressure in the middle of the contact zone drops to near zero with relatively low pressures each side. Circular ridges were machined in the contact area to encourage higher pressure 'knife edge' seal regions to be formed (see Fig. 6.).

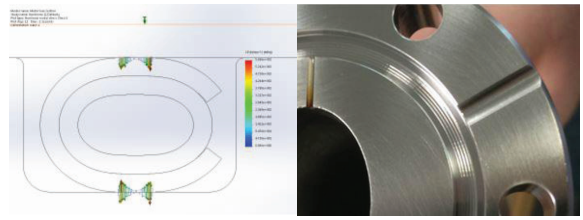

Figure 6: Machined ridges achieve higher pressures.

In reviewing the Helicoflex data tables for HN100, compression forces of 140-150 N/mm are shown for flanges DN40 and DN63 but 200 N/mm for larger sizes. Our view now is a minimum of 200 N/mm for all sizes.

Because the beam tube is oval, it is difficult to guarantee accurate alignment across flange joints minimising steps to <0.1 mm without the use of dowels. Dowels in the flanges require vessel separation so an external dowel arrangement has been developed instead (see Fig. 7.).

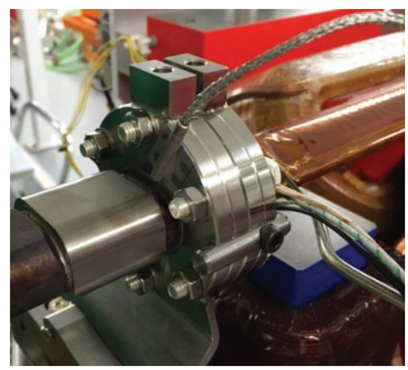

Figure 7: External dowel alignment of flanges.

Developments in electron beam welding of copper have allowed full penetration welds of cooling channels joined to the electron tube to be achieved without voids in the conduction path (see Fig. 8. left) and TIG welding of longitudinal joints in oval vessels with zero projection into the beam space (see Fig. 8. right).

Figure 8: Full penetration welding of copper.

The vessels are baked in-situ and during the assembly we unfortunately had a malfunction of the bake-out controller over a weekend which caused over-temperature damage to a number of vessels. This accident cost a month to programme to recover and repair vessels and valuable lessons have been learned including thermal switches now fitted to the vessels to trip the power.

GENERAL

A purpose built temperature controlled assembly room was constructed to accommodate both girders. This room is equipped with cooling water, magnet power supply and other services. In order to keep the shutdown to a minimum 8 weeks it was essential to complete off-line tests of magnetic field and cooling flows. Temperature control to 22+/-1 °C is essential for magnetic wire measurement and it was found that removing the roof to the room to enable a component to be delivered upset the stability and required 30 minutes for the air temperature to recover. It also became clear that mechanical, electrical, controls, survey, magnet and vacuum staff all needed competing access to one or both girders at the same time and the assembly room was just too small. For Diamond II a production line is required which respects the 3 different stages of magnet alignment, vacuum assembly and baking followed by cabling, pipework and test. Cables are routed on cable tray fixed to the girder with the cables terminated in a substantial patch panel (see Fig. 9.). This panel is replicated in the tunnel so that on installation the DDBA cell can be quickly connected, powered up and tested. This arrangement though is bulky and time consuming and is not attractive for Diamond II. The vacuum vessels are baked in-situ with the bottom of the magnets in place after alignment but with the magnet tops removed to install the vacuum vessels. The amount of cables involved with baking and temperature measurement is significant and they need to be included in the cabling design and 3D CAD model to route them tidily.

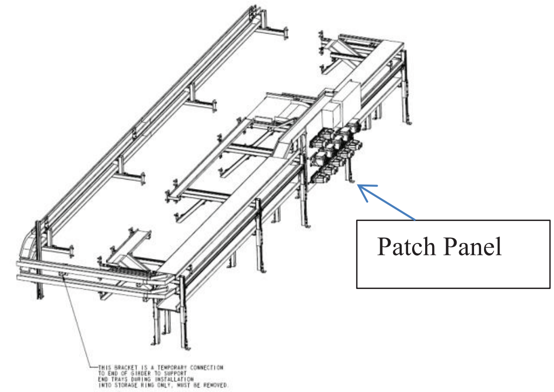

Figure 9: Arrangement of girder cable tray.

DIAMOND II

The DDBA project is proving that we can install a new straight section with an ID providing much more intense light through a previous Bending Magnet (BM) port. This principle can now be applied to the whole 24 cell storage ring effectively creating up to 48 straight sections available for the installation of IDs.

Along with many other light sources, Diamond is busy planning a low emittance upgrade to improve the brightness of the source. Reported in [5] is a proposal to reduce the emittance of Diamond from 2700 pm to 120 pm by building 24 Double Triple Bend Achromat cells (DTBA). A view of one cell of the DTBA lattice is shown in Fig. 10, with one of the new ID straights installed in the middle of the DTBA followed by an existing straight and ID.

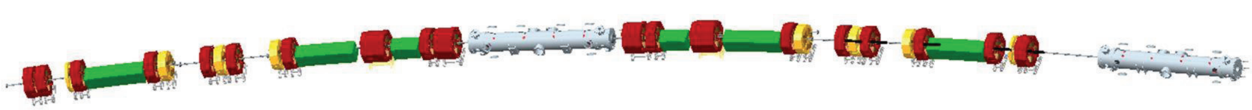

Figure 10: One cell of Diamond DTBA showing new ID position mid-achromat followed by an existing ID.

CONCLUSION

The DDBA project is about to be installed at Diamond creating a new ID straight and source point at a previous BM port. Many lessons have been learned in the practicalities of manufacturing water cooled, small bore, oval vacuum chambers of V22 mm*H29 mm external dimensions in copper and stainless steel, baking them in-situ and achieving face to face flange sealing with the Helicoflex© seal. Lessons have also been learned in the production of small, water-cooled electro-magnets and the essential requirement to achieve magnetic and geometric accuracy at the supplier to avoid delays during final assembly. Any major supply contract requires a dedicated client resource working continuously with the major suppliers.

The challenges on assembly and storage space should also not be underestimated. It is impracticable to manage multi-phase construction of complex girders side by side and a production line should be established with an overall responsible production manager to manage interfaces across many teams on a day-to-day basis.

A low emittance upgrade project is in progress and the lessons learned from DDBA will provide valuable information in planning the delivery of Diamond II.

REFERENCES

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[4] R.J. Smith, ''Evaluation of Hertzian and Finite Element Models of Elastomer and All Metal Spring Energised Seals'', Course Report, University of Central Lancashire, UK, April 2016.

[5] R. Bartolini *et al., in Proc. IPAC'16,* pp. 2943-2946.