MECHANICAL ENGINEERING OF THE DIAMOND DDBA UPGRADE

N P Hammond, A Day, R Grant, R Holdsworth, J Kay, Diamond Light Source, Oxfordshire, UK

Abstract

The Diamond storage ring has been upgraded to replace one cell of Double Bend Achromat (DBA) with a Double-Double Bend Achromat (DDBA). This upgrade has enabled the construction of a new straight to install a much brighter insertion device X-ray source for a new beamline rather than use a weaker bending magnet source. The engineering challenges and experience from this project are described, especially those aspects relevant to building a future low emittance storage ring at Diamond.

INTRODUCTION

The Diamond storage ring has been altered to replace one cell of Double Bend Achromat (DBA) with a Double-Double Bend Achromat (DDBA). This upgrade has enabled the inclusion of a new straight in which to install an additional Insertion Device to replace an unoccupied bending magnet beamline location. Some of the aspects of the design and manufacturing process are described.

STRATEGIC DESIGN CONSIDERATIONS

Initially the following design decisions were required:

- Retain the original girder adjustable support concept or trial an alternative.
- Assemble and bake completed vacuum vessels strings prior to installation on the girders, or assemble the vessels individually on the girders with bake-out elements, and bake in situ.
- Arrangement for magnet adjustment and alignment.
- The inevitable compromise on vacuum vessel aperture vs. magnet pole tip aperture.
- The use of distributed absorbers or discrete absorbers for the removal of unused light.
- The distribution of cooling water to the components, optimising heat transfer coefficient, but minimising potential high frequency vibration.
- Flange locations, alignment and sealing method.
- Non Evaporable Getter (NEG) internal coating or discrete NEG cartridge pumping locations.

Vacuum Vessel Size and Profile

The final vessel size of 29mmx20.4mm (HxV) elliptical profile and 1mm wall thickness proved to be the optimum dimensions to meet the following:

The decision not to have vessel antechambers but in order to simplify the vessel profile, have a plane elliptical vessel with internal wedge profiles to shadow uncooled downstream regions (see Fig 1).

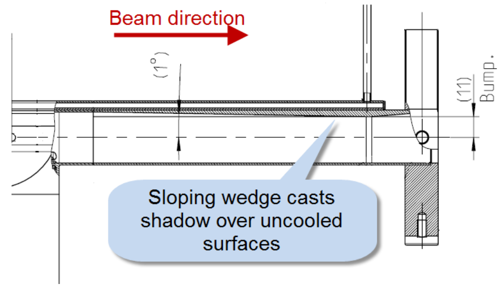

Figure 1: Internal wedge shadowing downstream uncooled regions

The requirement to increase quadrupoles field gradients from the existing 17.5T/m to 65 T/m resulting in a reduced pole tip circle diameter [1] (see fig 2).

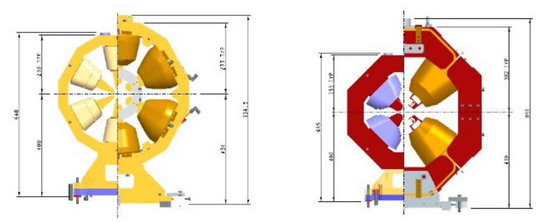

Figure 2: Comparison of existing multipole magnet size with the smaller DDBA magnet size

The optimum profile to maximise the clearance between the vessels plus heater jackets and the multipole magnet pole tips.

The requirement for a single design with possibilities to be located in a range of locations with differing Insertion Devices and canting angles in case of implementation in multiple DDBA cells (see Fig 3 and Table 1)

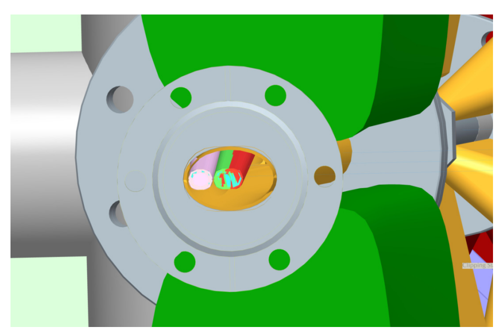

Figure 3: Potential Insertion Device light trajectories for various straight locations

Table 1: Insertion Device and Canting Angle

Location (Straight)	Type	Canting Angle (mrad)
2,3,4	Undulator	0.25, -0.75
5,6,8,10,21	Undulator	0.0
11,19,24	Undulator	1.5

An elliptical profile has the benefit of concentrating the vessel wall image currents towards the top and bottom of the profile away from the absorber features and pumping ports in the horizontal plane as illustrated in fig 4. This reduces beam perturbations arising from these features.

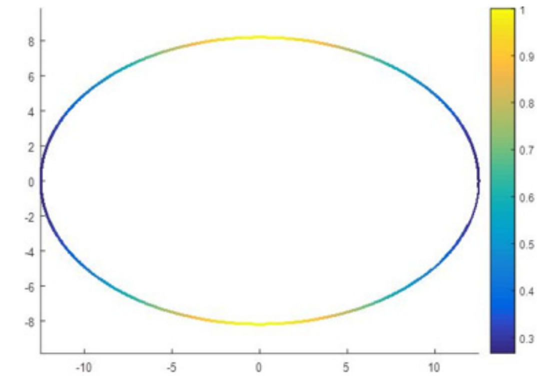

Figure 4: Normalised current distribution around vessel profile 'courtesy of G Rehm, DLS'.

Gasket Type and Sealing Loads

In order to ensure metal to metal contact across flange joints; and give no cause for cavities to trap electric fields resulting in perturbations to the orbiting electron beam, or arcing, a gasket retained in a groove was sought.

A sprung metal seal such as a Helicoflex® was trialled as a potential solution. This presented two other potential improvements in joint reliability.

1. A departure from the 'knife edge' style of seal.
2. Lower gasket sealing loads.

The equivalent sealing load for a Conflat® gasket is variously quoted as between 300 and 600N/mm using a DN100 as an example [2], (see fig 5)

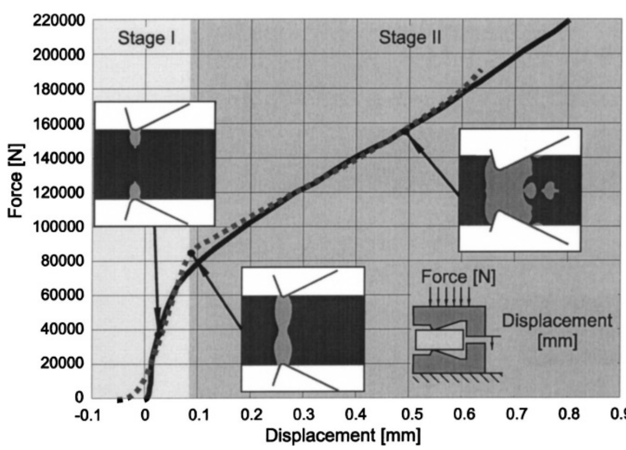

Figure 5: Example of required sealing load for a DN 100 Conflat® gasket.

The size and stiffness of the Helicoflex® seals can be modified to suit the application and consultation with the vendor resulted in the suite of seals shown in Table 2. These were incorporated into the flange designs.

Table 2: Seal Sizes and Sealing Loads.

Designation	HN100			
Flange DN#	40	63	100	160
Outer diam	48mm	82mm	120mm	171mm
Inner diam	43mm	75mm	114mm	164mm
Sect' diam	2.6mm	3.4mm	3.3mm	3.3mm
Contact diam	46mm	79mm	117mm	168mm
Sealing load (N/mm)	150	140	200	200
Compression load (N)	21,441	34,614	73,450	105,369
Maximum load (N)	43,416	105,408	210,816	263,530

The compression load refers to the force necessary to achieve the sealing load, the maximum load is the maximum recommended load available from the flange bolts (Class 80 Grade A5 stainless steel). The bolt sizes, pitch circle diameter, and number were the same as those for the standard Conflat® flange of the same size.

Initial problems were experienced with the DN40 seal in obtaining a reliable leak free joint. Much work was carried out in conjunction with the vessel manufacturer to try a variety of techniques to vary the surface finish of the flange groove surface. Both polishing techniques and machining techniques were varied. It was concluded that polishing of the sealing faces did little to improve the reliability, special tooling was helpful to ensure that a circular lay pattern was produced, as recommended by the seal supplier (see fig 6).

Figure 6: Seal face circular lay production.

The problems were only encountered with the DN40 seal and it was concluded that whilst care was required in preparing the seal surfaces, the characteristics of the seal such as section size and stiffness are equally as important. In order to maximise the contact area the seal section diameter should be ≥3.0mm and the sealing load should

ISBN 978-3-95450-182-3

be ≥200N/mm for a reliable UHV seal without requiring undue emphasis on surface finish.

VESSEL MANUFACTURE

Close work with the vessel manufacturer, FMB [3], produced good results. It was proved that complex copper and stainless steel vessels can be fabricated with appropriate accuracy. The correct tooling jigs and inspection gauges were important aspects of maintaining accuracy of form (fig 7).

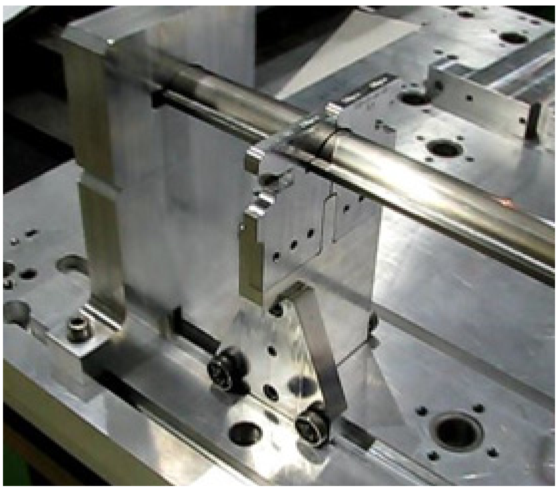

Figure 7: Vessel Inspection Tooling

The development of an automated welding process by the manufacturer was key to achieving repeatable high quality welds. All physical parameters were controlled to enable the work-piece to rotate with a variable rate to maintain a constant weld arc length and speed around the elliptical profile. The control was sufficiently sophisticated to compensate for eccentric rotation of the work-piece thus dispensing with the need to centre it in the machine (fig 8).

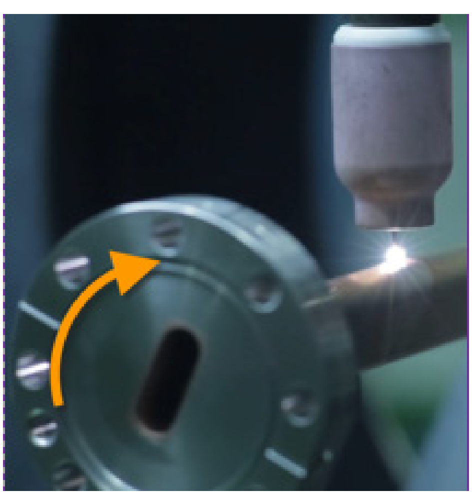

Figure 8: Automated vessel welding

The resulting circumferential butt welds had minimal weld cap and root penetration (fig 9), the latter being a vital feature of a vessel wall in close proximity to the circulating electrons.

Figure 9: Circumferential weld profile

Good liaison with the electron beam subcontractor produced welds with good material homogeneity in the welded joint between the vessel and the cooling channel where it is vital to eliminate voids in the zones of high heat transfer (fig 10).

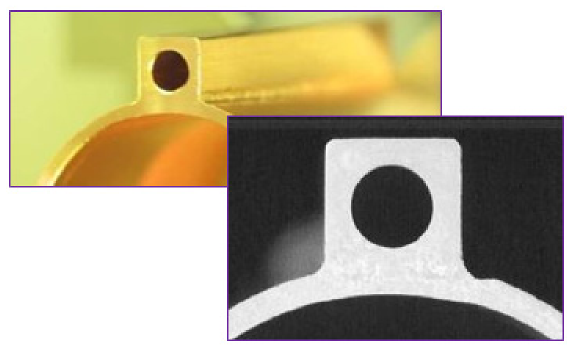

Figure 10: Homogenous weld in heat transfer zones.

CONCLUSION

A number of engineering challenges have been solved for the DDBA project specifically manufacturing small bore vacuum vessels, smaller scale magnets and assembly to high precision in an operating storage ring. All these design features, skills and valuable experience equip the Diamond team to look forward with confidence to constructing the next generation low emittance storage ring Diamond II.

REFERENCES

[1] R Bartolini *et al.*, in *Proc. IPAC'14*, Dresden, 2014, p. 322.
[2] P Lutkiewicz and Ch Rathjen, *JVSAF*, vol. 26, pp. 537-544, 2008.
[3] FMB GmbH, 2016, Berlin.