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ENGINEERING SOLUTIONS FOR THE DIAMOND DOUBLE DOUBLE BEND ACHROMAT PROJECT

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Abstract

The project to install a Double Double Bend Achromat (DDBA) providing an additional Insertion Device (ID) source for a new beamline at the Diamond Light Source is proceeding. This DDBA cell employs many of the technologies required for Diffraction Limited Storage Rings (DLSRs) and this paper describes the vacuum vessel, magnet and girder solutions in manufacture for the DDBA.

INTRODUCTION

Diamond Light Source has a 24 cell DBA lattice providing alternate ID and Bending Magnet source points for X-ray beamlines. Figure 1 shows how DBA cell 02 can be sub-divided into 2 smaller DBA cells, a 'DDBA' cell and thereby create space for an additional ID source point allowing 3 consecutive ID beamlines [1, 2].

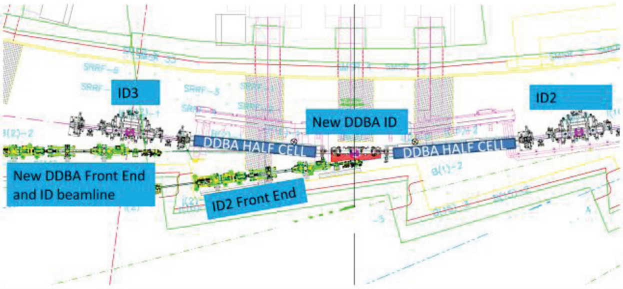

Figure 1: DDBA Concept applied to Diamond cell 02.

VACUUM VESSELS

The DDBA lattice requires quadrupoles and sextupoles with much higher strengths than the existing ones, which is a major reason for the reduction of the pole inscribed diameter from 78 mm to 30 mm. The vacuum vessel profile through the multipole magnets is shown in Fig. 2. There are 26 magnets and a 3.4 m straight in the same length as the existing 19 magnets in a DBA cell, which means the total lengths of all magnets are tightly constrained.

The elliptical shape allows a minimum of 1.5mm clearance to be maintained between the vessel and magnet pole tips in the quadrupole and sextupole magnets. The wider horizontal dimension is also beneficial in synchrotron radiation ray-tracing as it allows the dipole rays to travel further and reduce in intensity before being absorbed on the water cooled outer surface. A further benefit of the wider dimension relates to reducing beam impedance and heating effects at vacuum pumping slot locations around the cell as well as in the 'Crotch' absorber where useful X-rays are separated from the circulating electron beam. Predicted image current densities on the inside surface of the vessel are a factor 2.5 greater above and below the beam compared with the sides. To prevent beam heating of vessel flanges the current preference is to use the Helicoflex© seal to avoid any gaps between flanges on the electron beam path. All other flanges will use the usual Conflat© copper gasket.

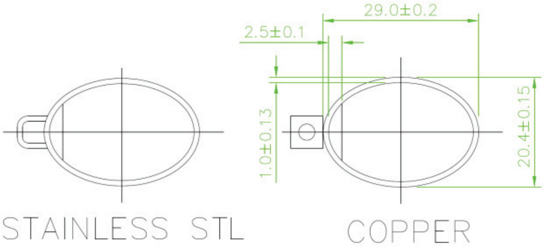

Figure 2: DDBA vessel cross-section.

The elliptical cross-section has been produced in both stainless steel for vessels passing through corrector magnets (integrated into the sextupoles) and copper for use in dipole and quadrupole locations where thermal conductivity is more important and there are no rapidly changing magnetic fields.

VACUUM PUMPING

At the outset of the DDBA project it was intended to coat all the vacuum vessels with Non-Evaporable Getter (NEG) material in order to achieve the pumping speeds and base pressures required in such small aperture vessels. Due to the complexities of cleaning vessels to the required standard and applying the NEG coating at the correct thickness and uniformity as well as a lack of industrial suppliers, it was decided to revisit this approach and now an acceptable solution has been designed employing discrete NEG cartridge pumps with ion pumps in the crotch locations where the photon desorbed gas load is greatest. See Fig. 5 for a view of the vessels in a half DDBA cell and Fig. 3 for the calculated CO equivalent pressure around the cell after 100Ah conditioning at 300mA beam current. The DDBA cell of course benefits from pumping in the adjacent ID straight sections in the ring and the very low pressures due to the well pumped ID located in the centre of the cell.

The NEG cartridge pumps will be equipped with internal heaters to allow *in-situ* regeneration. The vacuum

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vessels will be baked to 250°C at the factory and then 200°C during first assembly with the magnet tops removed and the dipole magnets withdrawn to the side. Within the magnet 1.5mm pole tip clearance, the vessels will be permanently fitted with heater tapes of 0.6mm thickness delivering 1.6W/cm^2 and then wrapped in 2 layers of 0.2mm Kapton insulation which will provide a ΔT of 40°C. Any re-baking in service is planned to be carried out at 200°C max with multipole magnets fully assembled to avoid the risk of introducing any magnet alignment errors but this is dependent on the results of baking trials currently in progress to measure the temperatures reached in the magnet pole tips.

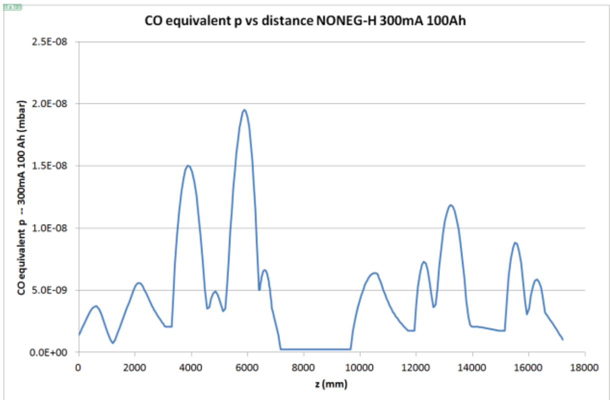

Figure 3: Predicted pressures around the DDBA cell.

RAY-TRACING

Detailed ray-tracing has been carried out to determine which surfaces will be illuminated by synchrotron light from existing dipole magnets and IDs upstream of the DDBA cell and from dipoles and ID within the cell. An added complexity is that the DDBA cell could be inserted at a number of locations within the existing SR and many straights are already equipped with different canted ID arrangements. The ray-tracing has taken account of these canted ID angles so that the flexibility of installing the cell at many locations around the ring is maintained.

For the Heat Transfer Coefficient in the water cooling channels a value of 0.02Wm^{-2}K^{-1} has been applied equivalent to a flow speed of 4-5m/s in the vessel cooling channels. The maximum temperature of the cooling water is limited to 165°C, the boiling point of water at 6barg which is the lowest water pressure measured.

For extruded copper tube the alloy is CuAg(0.1) which has much better strength than pure copper. For linear elastic analysis the design membrane stresses have been limited to 90MPa at ambient temperature and 60MPa at 250°C. Because of the tendency for copper to become soft when annealed, if an elasto-plastic analysis is required, a further design limit is for peak strain to be < 0.5% and 0.1% membrane strain [3]. Acceptable temperatures are generally set at 100°C inside the vacuum vessels but with an upper limit of 400°C for copper crotch absorbers. For austenitic stainless steel (SS), because it is much less ductile, high stresses are reached at relatively low temperatures. Stress intensity from linear elastic analysis must not exceed 196MPa for 316L at ambient temperature, decreasing to 167MPa at 100°C. If calculated stresses for 316L approach these values then a more local and detailed analysis and stress linearization through the wall thickness is undertaken with limits on local membrane + bending stresses of below 294MPa at ambient temperature and 250MPa at 100°C. When considering peak surface stresses against the fatigue failure criteria of 8000 cycles (equivalent to 30 years operation) for 316L then at 100°C the limit is 315MPa. The plastic strain stress criteria for copper is more exacting than an elastic fatigue limit for the stresses applied at <10^4 cycles.

In the design of the vessels (Fig. 2), a water cooling channel will be welded to the side of the vessel illuminated by synchrotron radiation but of course this channel has to be discontinued where vessel flanges are positioned. Upstream of these locations an internal taper has been added to the vessel internal wall which reduces the side wall profile by 2.5mm and casts a shadow across the flange joints. The combined impedance effect of 8 of these tapers is negligible.

Finite Element Analysis is carried out using ANSYS and based on beam current of 550mA to give a 10% margin over the maximum planned operating current. As an example, Fig. 4 shows the ray-tracing, power loads and analysis output for the copper crotch absorber downstream of dipole 3. Maximum temperature is 237°C.

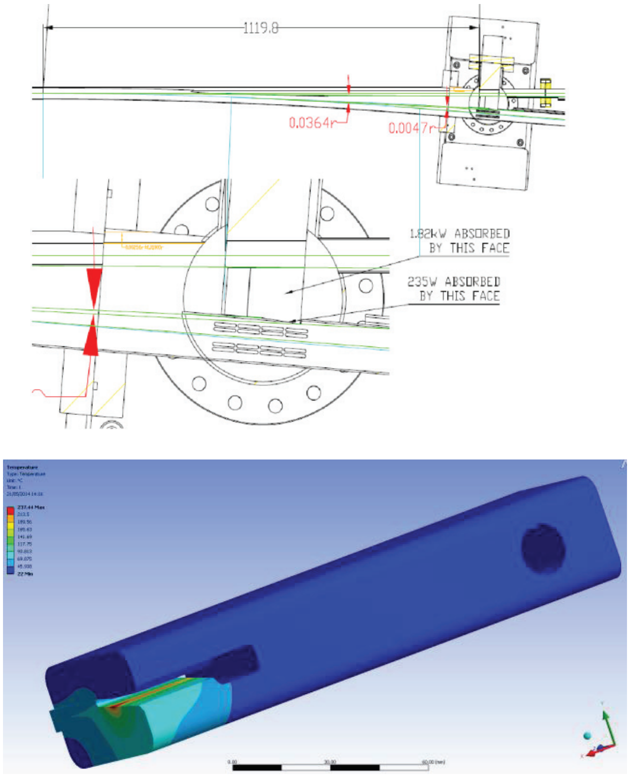

Figure 4: Ray-tracing and analysis of Dipole 3 crotch.

Figure 5: Vacuum vessels of the upstream half of the DDBA cell.

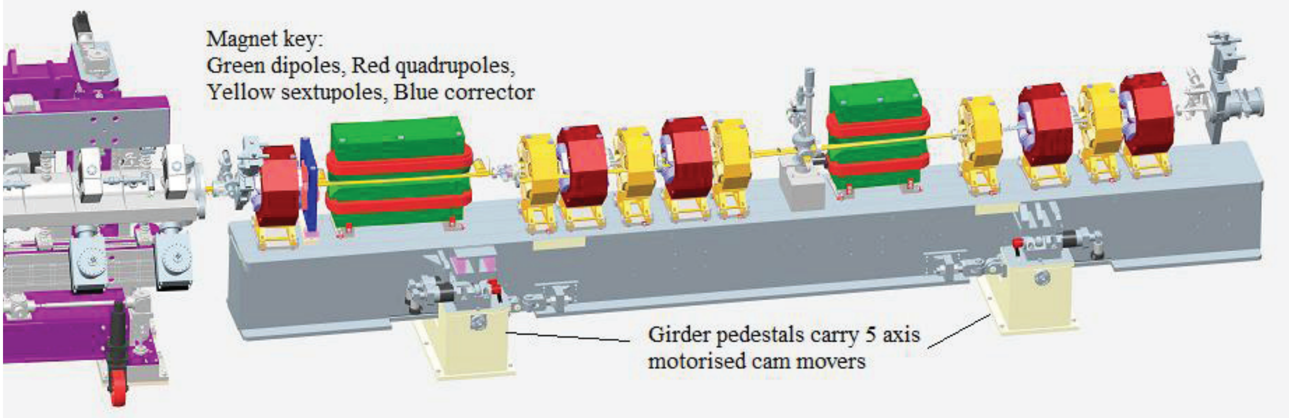

Figure 6: Magnet, vessel and girder assembly of the upstream half of the DDBA cell.

GIRDERS

The magnets [4] and vessels of the DDBA cell will be mounted on 6750mm long girders equipped with motorised cam movers to allow remote 5 axis adjustment. This is established technology at Diamond [5] with 72 such girders installed and experience gained in swapping out existing girders with ones that have been pre-assembled with special magnets for IR extraction for example or the ‘Double mini-β’ upgrade [6].

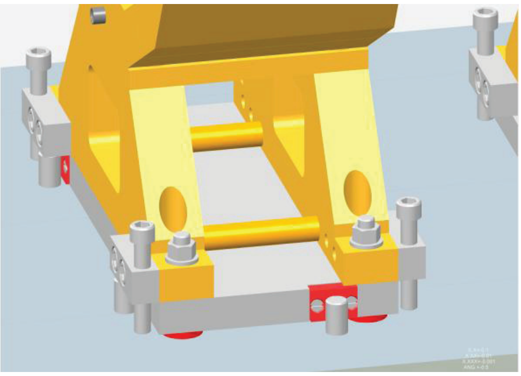

Figure 7: Magnet mounting features.

The magnets will be measured and fiducialised at the factory using a stretched wire method. They will then be mounted on the girder with a system of shims, packing pieces (shown in red Fig. 7) and dowels with dimensions set by the magnet measurement. The stretched wire method will be used again to check the alignment of the groups of 4 and 5 multipole magnets shown above.

CONCLUSION

The DDBA project to provide additional ID beamlines at Diamond is well advanced in design and procurement. The first DDBA cell is planned for installation in Aug’16.

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