Mechanical Engineering Solutions for the Diamond Double Double Bend Achromat Project

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Abstract - In order to allow more Insertion Devices (IDs) to be added to the Diamond storage ring in the unused bending magnet (BM) beamline locations, a new cell configuration project is underway. Named a Double Double Bend Achromat (DDBA), the magnetic lattice is being modified and rearranged to provide space for an additional ID location near the middle of an existing achromat cell. The DDBA cell employs many of the concepts which are required for a proposed lower emittance storage ring upgrade and so gives an opportunity to gain valuable experience in these technologies. This paper describes some of the features incorporated into the design of the magnets, vessels and girders of the new storage ring cell configuration.

Keywords: Diamond, low emittance, DDBA

1. Introduction

Many 3rd generation light sources are designed around the Double Bend Achromat (DBA) where the magnet lattice for each individual cell of the storage ring employs a straight section followed by a bending section using 2 dipole bending magnets. This in turn allows for ID radiation to be extracted to a beamline from the first dipole with the second dipole providing radiation to a BM beamline. ID radiation sources are far more intense and attractive to scientists than BM sources and so it would be advantageous to reconfigure the DBA cell to include a second ID in between the 2 dipoles. There is also a great deal of interest now in building much higher brightness Diffraction Limited Storage Rings (DLSRs) which generally employ Multi-Bend Achromats (MBA) whereby the horizontal emittance is reduced in inverse proportion to the cube of the number of bending magnets, Eriksson et al., (2014).

Combining both ideas as options for future developments of Diamond, it became apparent that an MBA cell using 4 dipole bends could be split in the middle to make space for an additional ID and in this way two smaller DBA cells have been created and hence the name of the project Double DBA! Ref' Fig. 1, Walker et al., (2014). Diamond is approaching the end of its Phase 3 beamline development which would deliver a total of 32 beamlines. One of the Phase 3 beamlines for Versatile Macromolecular Crystallography (VMX) was planned to deliver 2 techniques of microscopy and in-situ diffraction sourced by 2 canted IDs in one straight, one 2m long and the other 0.75m long. With DDBA, both techniques can be separated and sourced on 2m IDs in separate straights.

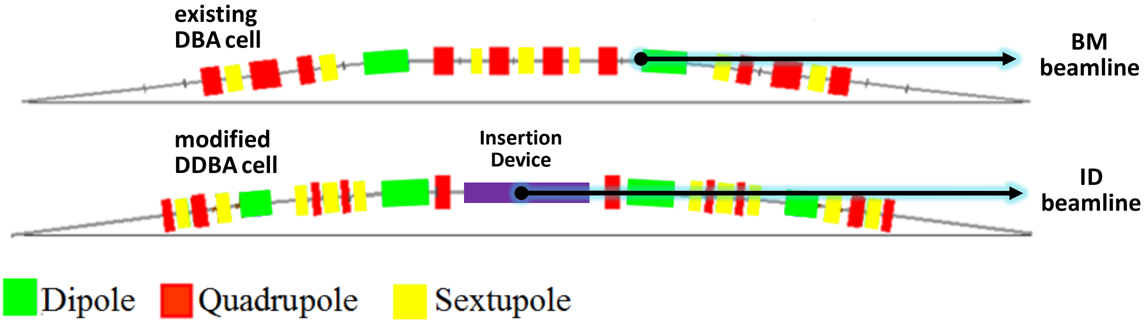

Fig. 1. Schematic diagram of the existing DBA and modified DDBA cells

2. General Layout

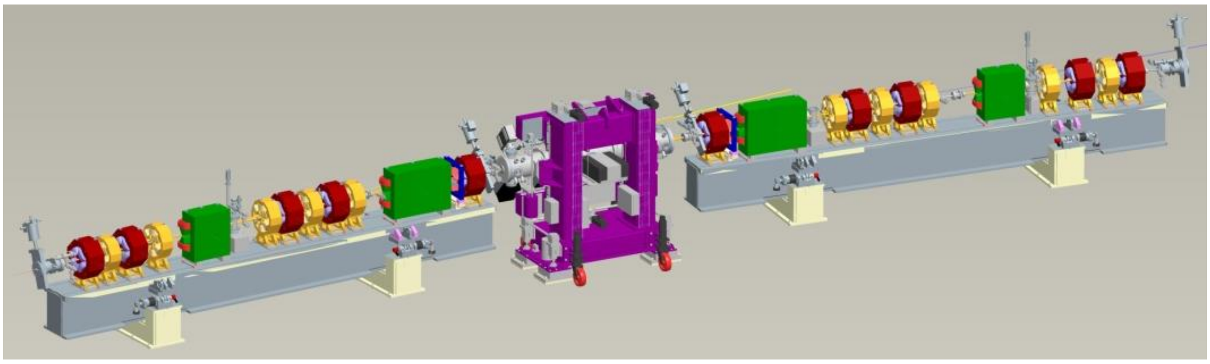

Fig. 2 View of the whole DDBA cell including an ID in the new straight section

Figure 2 gives a view of the whole DDBA cell. Due to compressed timescales and good experience gained building Diamond, the decision was made to utilise discrete magnets mounted on long girders, rather than integrated magnets and girders as pioneered at MAXIV. The process of removing the 3 existing girders for a cell at Diamond is well established with girder lengths typically 6m and weight 17T. The 2 new DDBA girders are 7.5m long and each weigh 10Tonnes. The floor pedestals and girder mover system will be reused after being repositioned to the new geometry. The girder mover cam height will be reduced from the existing 7mm down to 1mm. This reduction in cam height is justified for 2 reasons. The experience over some years now of the stability of the storage ring floor shows that a vertical band of 1mm includes all the measured height variations around the 562m circumference so large displacements are not required. A 1mm cam height will generate maximum displacements of 2.46mm within the inter-girder bellows which connect vacuum vessels at the end of each girder. This range of motion can be accommodated in a spring finger RF bellows design without the need for complex limit switches which are employed at the moment.

A design principle is that if DDBA does not work for some reason, then the previous DBA cell should be replaceable. This principle places particular demands on cable and pipe service routes and capacities.

3. Magnets

A design principle for DLSRs using MBAs is that the magnets must achieve greater field gradients than normal and for DDBA, Bailey et al (2014) describes Quadrupoles at around 70T/m and Sextupoles at 2000T/m^2. To achieve these gradients using conventional water-cooled copper windings and iron poles requires the inscribed magnet aperture radius to reduce from 39mm in Diamond down to 15mm for DDBA. Because there are more dipole bends, the dipole field actually reduces from 1.4T to 0.8T but to make the optics work, the dipoles are combined magnets with tapered poles to create a quadrupole field. To achieve the required dipole and quadrupole fields the dipole gap reduces from 46.6mm in Diamond to 30mm in DDBA.

The magnets will be mounted to the top of the girder with a shim and dowel pin system shown in Figure 3, allowing the magnets to be fixed in position, height and roll to meet the specification in Table 1. For the dipole in particular a larger range of accurate positioning is required to fine tune the combined quadrupole field. There is also a requirement to with draw the dipoles by 125mm in order to install the dipole vessels.

Table 1. Specification of magnet positioning system

Transverse Range Dipole Multipoles Resolution	 ±2mm ±1mm ±10µm
Vertical Range Resolution	 ±1mm ±10µm
Roll Range Resolution	 ±4mrad ±40µrad

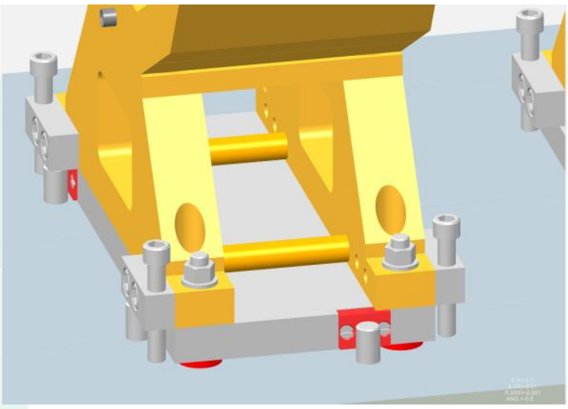

Fig. 3. Magnet mounting arrangement

The dipoles will be measured by a Hall probe bench but the multipole magnets will be measured by a stretched wire bench purchased from the ESRF. This stretched wire system will be loaned to the magnet supplier together with a short girder as shown in Figure 4, to measure each magnet at works and derive dimensions for the height and thickness of shim packs that will be used to position the magnet on the girder. The stretched wire system will then be returned to Diamond and used to check the alignment of each multipole magnet when assembled in groups of 4 and 5 on each DDBA girder as can be seen in Fig. 5. It is important in this process to take account of the slope of the girder induced by its deflection when mounted in the pedestals as well as the contribution of dipole magnets to that slope because the dipoles will have to be removed to make way for the stretched wire mounting towers. There is a deflection of 20µm due to the self weight of the girder and this will be compensated for by final machining the girder top flat whilst it is supported at the pedestal support points.

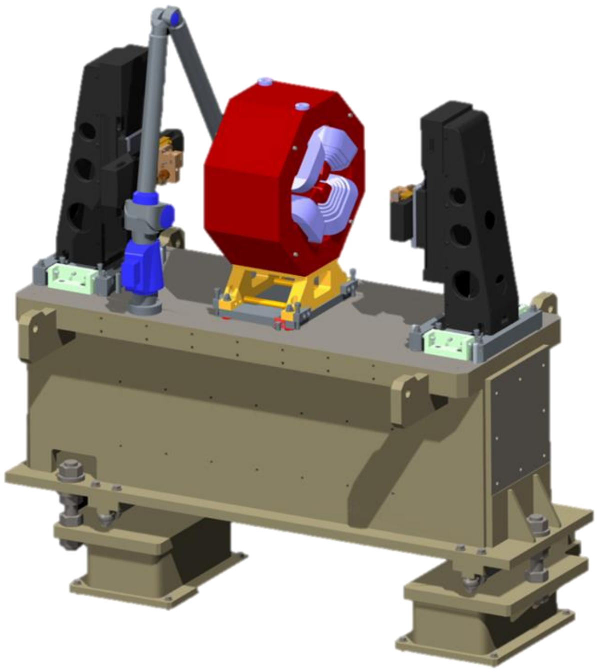

Fig. 4. Magnet measurement arrangement at works

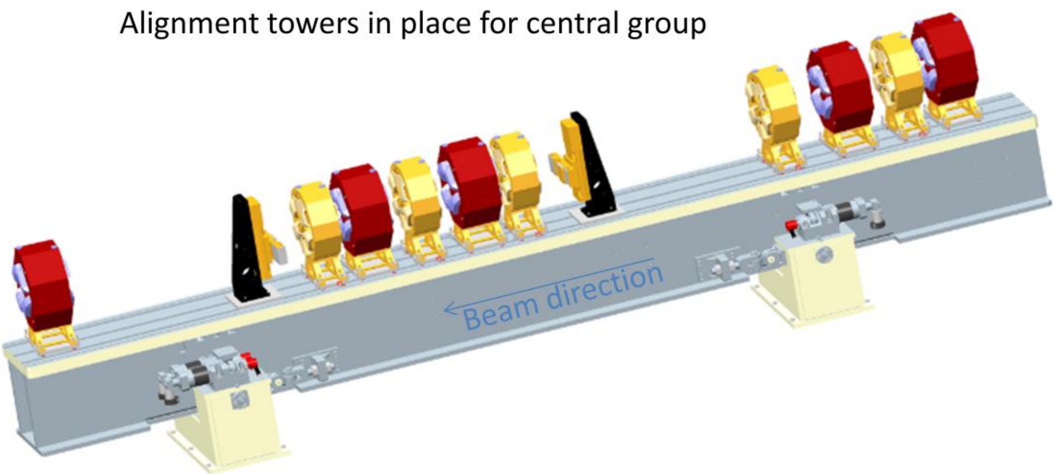

Fig. 5. Magnet measurement of multipole groups on the girder

4. Vacuum Vessels and Pumping

The constraints on magnet design described in section 3 requiring small apertures for higher fields mean that the vacuum vessels in turn also need to be of much smaller cross-section, Kay et al (2014). Figure 6 details the cross-section of the DDBA vacuum vessels. Extrusions in both copper and stainless steel have been purchased to provide the basic component of each vessel sub-assembly. Copper would have been attractive to use throughout DDBA but each of the yellow sextupole magnets are also fitted with AC corrector coils and in order not to attenuate these corrector fields, stainless steel vessels are required to pass through them. During the detailed FEA and ray-tracing design stage it became apparent that acceptable temperatures and stresses could not be achieved in the water-cooled stainless steel in some locations. A proposal not to use correctors in 2 of the sextupoles was accepted by Accelerator Physics and in these locations copper vessels now give acceptable temperatures and stresses. It is proposed to electron beam weld the cooling channels to the extrusions in both copper and stainless steel.

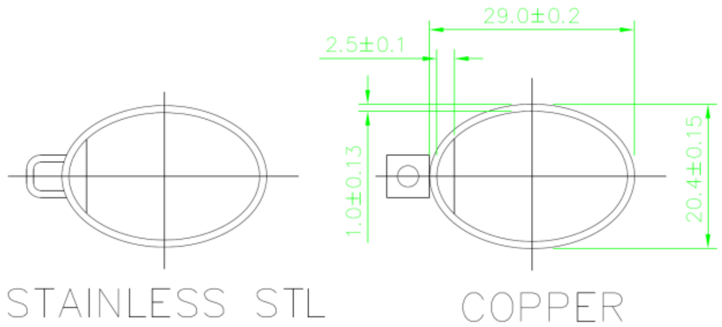

Fig. 6. DDBA vessel cross-sections

After extensive testing, the decision has been made to employ the Helicoflex© style of spring reinforced metal seal shown in Figure 7 on flanges that surround the electron beam. This is because this style of flange can be guaranteed to have zero gaps in the flange joint. These gaps are the source of beam heating effects which are made worse by the smaller cross-section. Extensive tests on all sizes up to DN63 have included repeated baking and asymmetric heating across the flange. Flanges that are off beam axis will employ the traditional and cheaper ConFlat© silver-plated copper gaskets.

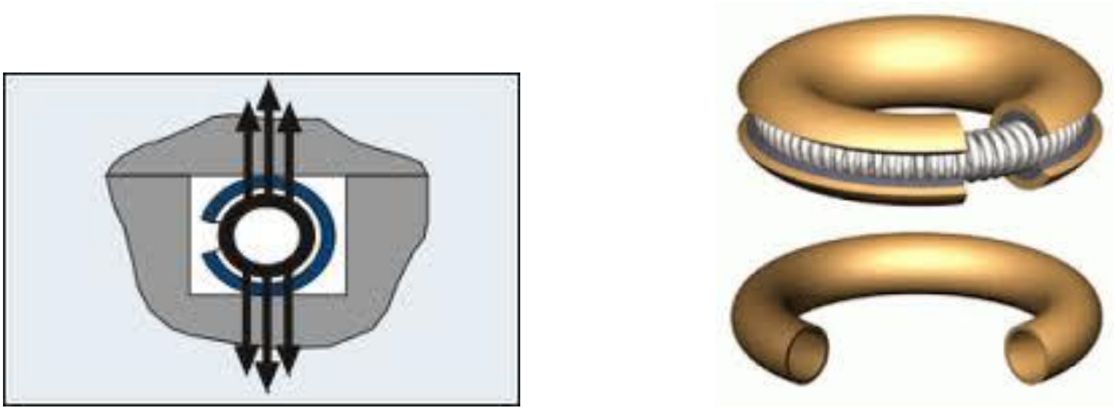

Fig. 7. Helicoflex© spring reinforced all-metal seal

In the detailed ray-tracing it became quickly apparent that in the smaller horizontal cross-section of 29mm compared with the 84mm typical of Diamond, dipole rays were falling at a closer distance onto the un-cooled flange joints. A solution to this is to thicken the wall local to the flange and create a cooled 'bump' to cast a shadow across the flange. The maximum internal height of this bump is 11mm from the beam centre line so as not to invade the beam stay clear aperture. Eight of these bumps have been employed around the DDBA arc in both materials. A further benefit of DDBA is the field in the dipoles reduces from 1.4T to 0.8T. Since dipole power scales with field, the dipole power density at 3GeV and 550mA (500mA max' operating current + 10%) reduces from 338 W/mrad^2 to 193 W/mrad^2. Figure 8 shows a typical distribution of dipole power around dipole 2 at 550mA.

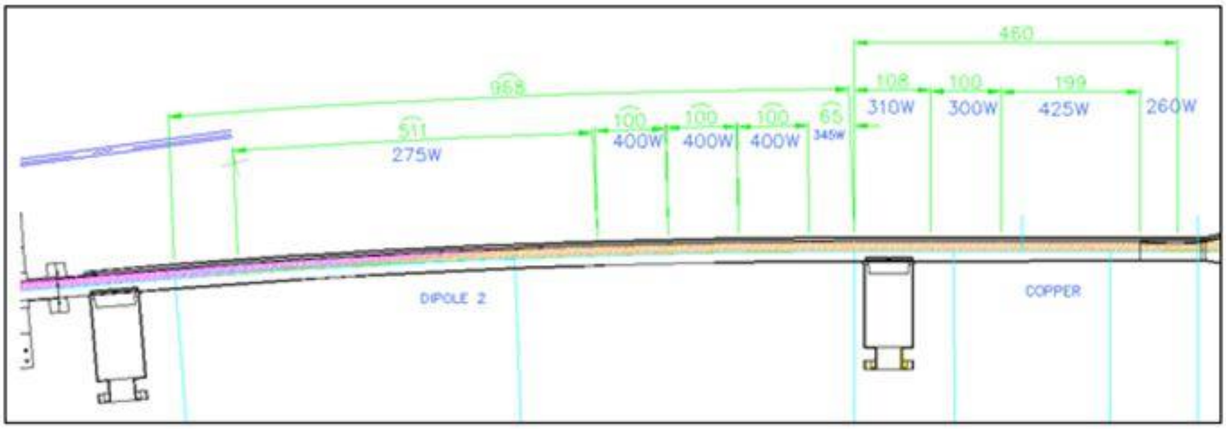

Fig. 8. Power distribution around dipole 2 vessel and with bump fitted at exit flange

For water cooled copper vessels max temperatures and stresses of 70°C max and 29MPa are typical with distribution as shown in Figure 9. In stainless steel 100°C max and 100MPa are more typical, as described in Hammond et al (2014). Ray-tracing has also included the photon exit tubes and the 2 crotch absorbers. For the crotches, a traditional approach using water cooled fingers to absorb dipole radiation and create a cooled window for the ID radiation to pass through gives good results with a maximum temperature of 237°C.

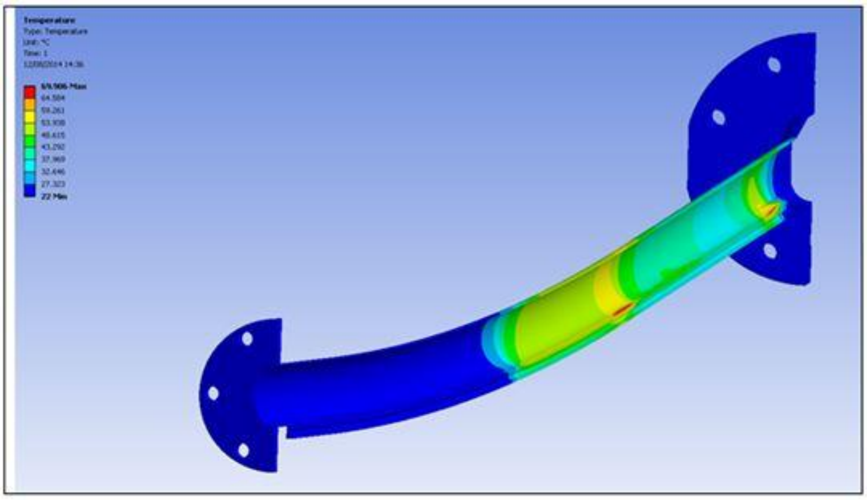

Fig. 9. FEA result for dipole 2 copper vessel 70°C max and 29MPa

The ends of the vacuum string are equipped with larger valves to mate with the rest of the existing storage ring. Consequently there are some large taper sections which employ a design rule of 1:10 maximum taper angle generally, although in some tapers this has been relaxed to 1:5 because of the limited length available for the transition.

The vacuum vessels will be fabricated at works and mounted on vessel stands included in the contract. After mounting the multipole magnets on the girder and measuring them with the stretched wire system, the magnet tops will be removed and the dipoles will be fitted and withdrawn radially to the side. Figure 10 shows how the individual vacuum vessel assemblies will then be mounted into the magnets and flanges bolted up. In this position the vessels will be baked to 200°C in-situ. The dipole vessels will be wrapped in conventional heater tape and foil jackets. Figure 11 shows how the vessels through the multipoles will be permanently fitted with integrated heaters and 2 layers of insulation measuring 0.68mm thick in total leaving typically >1.0mm pole tip clearance in the magnets. Some bake-out tests have been carried out at 200°C and show that magnet poles will reach 40-60°C during bake which is acceptable.

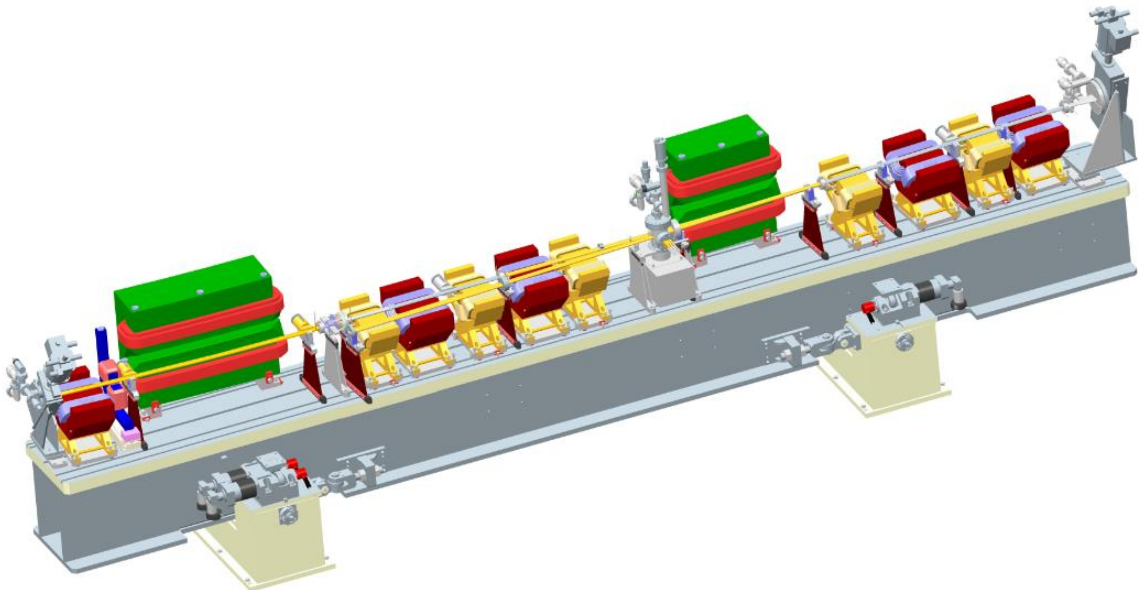

Fig. 10. Upstream girder with magnet tops removed and dipoles withdrawn to fit vacuum vessels

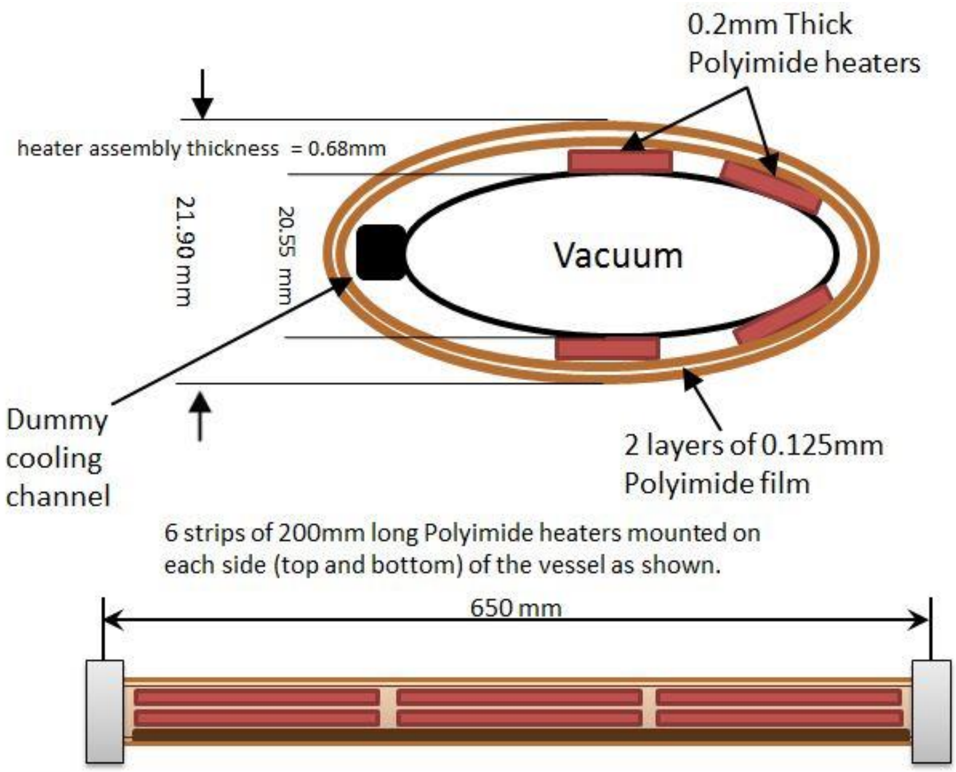

Fig. 11. General arrangement for bake-out heaters and insulation

Acceptable vacuum pressures are achieved with pumping provided by NEG cartridges and 3 ion pump locations underneath the crotches. At the ends of each DDBA girder further pumping is provided by connection to existing straight sections or the newly created straight which are all well supplied with ion pumps. Distributed pumping by NEG coating the vacuum vessels was deemed too risky for the DDBA project as there is only a small supplier base available.

5. Conclusion

The Diamond DDBA project is well advanced with major contracts let for magnets and vacuum vessels. The project employs well established techniques of pre-assembled magnets and vessels on girders so that the removal of an existing DBA cell and the installation and commissioning of a new DDBA cell can take place during a 2 month shutdown which is scheduled for summer 2016.

Whilst the DDBA project aims to deliver an additional ID straight for a new VMX microscopy beamline, it is also useful in developing techniques and gaining experience in technologies relevant to a future DLSR upgrade to Diamond which could be implemented early in the next decade.

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