# STUDY OF THE POSSIBILITY OF IMPLEMENTING A SUPERBEND IN THE DIAMOND LIGHT SOURCE

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*Abstract*

We report on recent studies of the feasibility and impact of replacing one of the regular 1.4 T bending magnets in Diamond with a normal conducting 3 T "Superbend" in order to enhance the hard X-ray output for a possible future beamline. We describe the preliminary magnet design, the vacuum and engineering implications and the effect on beam dynamics.

## INTRODUCTION

One of the proposed future bending magnet beamlines for Diamond, "DIAD" - Dual Imaging And Diffraction, requires high photon flux in the 4-40 keV range. The standard bending magnets have a magnetic field of 1.4 T and hence a critical photon energy of 8.4 keV. In order to enhance the flux at higher energies the proposal is to replace one of the bending magnets with a 3 T "Superbend", thereby increasing the critical energy to 18 keV. Figure 1 shows the increased brightness of the radiation produced by the Superbend, up to a factor of 6 at 40 keV.

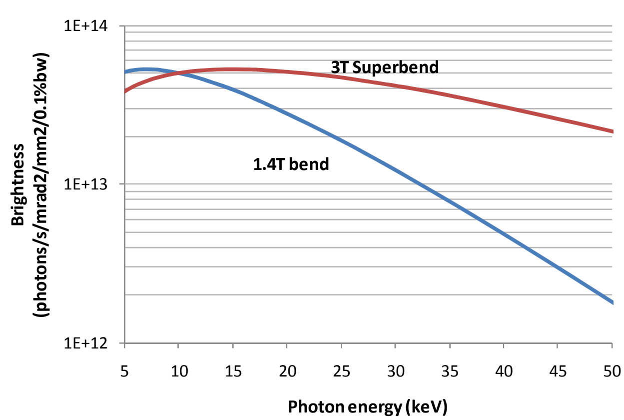



Figure 1: Radiation brightness for a standard bending magnet and the proposed Superbend in Diamond (3 GeV, 300 mA).

Superbends have been successfully installed in the ALS (5T superconducting magnets) [1], and the SLS (2.9 T normal conducting magnets) [2]. In both of these cases the central dipoles of the triple-bend achromats were replaced, and the radiation source points were close to the centre of the magnets and so near the peak field region. In the case of the SLS this conveniently allowed a magnet to be designed with short central high field region flanked by 1.5 T end regions [3]. Diamond however has a double-bend achromat lattice with the radiation source point being close to the entrance of the second magnet in the arc. A Superbend of the SLS type cannot therefore be used, since the field must increase rapidly at the ends so that it reaches close to 3 T at the radiation source point.

## MAGNET DESIGN

The first concept for the magnet design was motivated by the desire to be able to install the magnet around the existing dipole vacuum vessel, which restricted the pole gap to that of the existing magnet, 46.6 mm, and also required a similar C-frame yoke for ease of installation. A pumping spout further restricted the vertical separation of the coils as can be seen in Fig. 2.

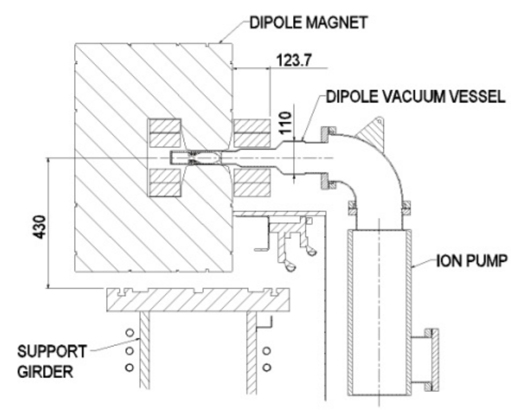
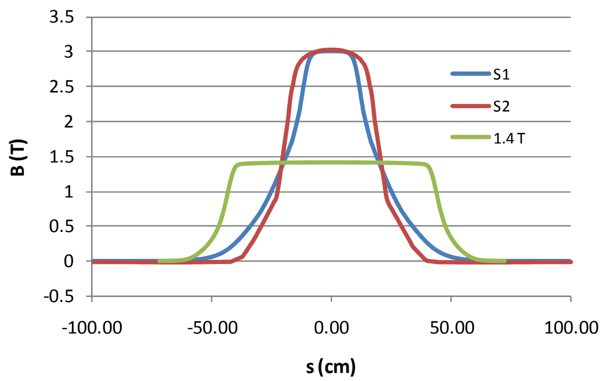



Figure 2: Existing dipole magnet and vacuum vessels.

Calculations with OPERA 3D confirmed that a field close to 3 T could be obtained with this geometry, but with a number of drawbacks: very high power consumption of 170-180 kW (compared to 10.7 kW for a standard bending magnet), and slow ramp-up of the field, resulting in a field of only ~1.9 T at the beamline tangent point (~25 mrad) (see Fig. 3). In addition, examination of the impact of installing such a magnet also revealed a significant clash between the return yoke of the magnet and the front-end of the upstream insertion device beamline.

To solve these problems it was decided to abandon the restriction of using the existing vacuum vessels, and also to use an alternative H-frame magnet design. Beam dynamics/lifetime considerations require a vertical "beam stay clear" of 25 mm, from which a revised pole gap of 33 mm was derived (3 mm vessel thickness + 1 mm clearance/flatness per side). The resulting design is shown in Fig. 4. The yoke thickness on the outer side (35 mm) was determined by the requirement to not exceed the dimension of the existing dipole and therefore to eliminate the clash with the adjacent front-end. The yoke thickness on the inner side is 145 mm.

The new design results in a reduced power dissipation of 105 kW and a field of 2.82 T at the tangent point (see Fig. 3, "S2"), considerably better than the initial larger gap, C-frame design. Table 1 summarises the main parameters of the magnet.



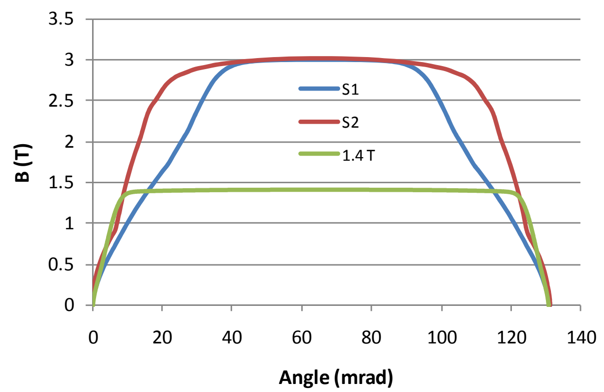




Figure 3: Field vs. distance (upper) and angle (lower) for the existing 1.4 T bend magnet and the initial (S1) and latest (S2) design of Superbend.

## NEW VACUUM VESSEL DESIGN

### *Vacuum Conditions and Pumping Requirements*

The proposed Superbend vacuum vessel will be similar to the standard dipole vacuum vessel but with the internal height reduced from 36 mm to 25 mm within the magnet pole area. The local pressure in the beam channel will be higher than in the standard case for two main reasons. Firstly, although the total photon flux is the same the critical energy is increased and higher energy photons are more efficient at causing photon stimulated desorption (PSD); the PSD yield is roughly proportional to the critical energy [4]. Hence there will be higher beam-induced out-gassing from downstream vacuum vessels and absorbers. Secondly, the reduced internal height reduces the molecular flow conductance of vessels and pumping manifolds which reduces the local effective pumping speed. These two effects have been simulated using the Diamond "Pressure Profile" code [5].

Without stored beam, the calculated maximum pressure in the Superbend dipole vessel is $3.7 \times 10^{-10}$ mbar, almost

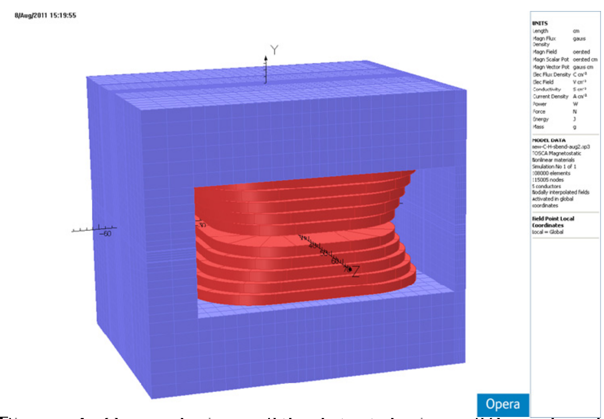



Figure 4: General view of the latest design of Superbend.

Table 1: Main Superbend Parameters

| | |
|---|---|
| Peak field | 3 T |
| Pole gap | 33 mm |
| Pole/yoke length (Z) | 386/840 mm |
| Pole width (X) | 160 mm |
| No. of coils | 2 |
| No. of turns/coil | 130 |
| Current | 1353.5 A |
| Conductor cross-section | 14 x 15 mm, 8 mm diam. |
| Current density | 8.5 A/mm$^2$ |
| Voltage | 78 V |
| Power | 105 kW |

identical to that in the standard vessel. With 500 mA stored beam (the future operational target), after 100 Ah of conditioning, the localised peak pressure near the crotch absorber is $1.7 \times 10^{-9}$ mbar compared with $1.4 \times 10^{-9}$ mbar in the standard vessel. Furthermore, the pressure only increases marginally to $1.85 \times 10^{-9}$ mbar if the side pumping is removed completely. The average pressure along the whole 22 m storage ring cell is increased by only 8% from $8.3 \times 10^{-10}$ mbar to $9.0 \times 10^{-10}$ mbar which is within the $1 \times 10^{-9}$ mbar target pressure. Calculations for initial conditioning after 10 Ah of beam dose show a more marked increase in pressure in the Superbend case, of the order of a factor of two, but the effect of omitting the side pumping remains very small (~8%).

The current plan is therefore not to replicate the side pumping in the new vessel design, which will greatly simplify the vessel design and construction, as well as the magnet design and overall assembly.

### *Engineering Design*

The reduction in vertical aperture in the vessel means that the slit absorber which is present in both dipoles in the achromat needs to be removed. This is not a problem however as it was only included in the dipole 2 vessels to keep all vessels identical and is not strictly needed as there is no upstream insertion device. A modified dipole 2 vessel with no slit absorber has already been installed in one location in Diamond to permit a larger vertical angular range to be extracted for an IR beamline.

The entry and exit apertures of the new dipole vessel will remain unchanged to match adjacent vessels. The portion of the vessel which passes through the magnet pole tips will have its external height reduced from 44mm to 31mm in order to maintain the same clearance between magnet pole tip and vessel as for the standard dipole. Tapers to change height from standard vessel cross section to the reduced section will have to be included.

An important issue is the increased power of the emitted radiation. The crotch absorber collects radiation emitted at angles between 25 and 79 mrad in the standard dipole, determined by the requirement to shadow the walls of the downstream X-ray and electron vacuum vessels. In the Superbend case the geometry is modified and the crotch absorber needs to be wider in order to shadow the X-ray leg, and it then is hit by radiation emitted between 27 and 90 mrad. The total power incident on the crotch increases from 4.3 to 10.8 kW at 500 mA, while the peak power density increases from 632 W/mm$^2$ to 1292 W/mm$^2$ (in normal incidence). The effect of this has been simulated by finite element analysis using ANSYS and the results indicate a peak temperature 765 $^o$C and an elastic stress of 506 MPa. Therefore, a new design of the crotch absorber is under consideration, decreasing the angle of incidence and/or changing material from OFHC Cu to Glidcop© or CuCrZr.

## POWER SUPPLY

The coil parameters have been adjusted so that the current is nominally the same as that of the existing dipole circuit. A trim coil will however be included in the magnet design to remove any residual closed orbit distortion. With the Superbend magnet the output voltage of the power supply will go up from 398 V at present to 476 V. Given that the DC Link Voltage is over 750 V this still leaves plenty of headroom for regulation. The 11 kV transformer is presently running at about 700 kVA, and this would increase to about 850 kVA, however this does not pose a constraint as it is rated at 1300 kVA.

## ACCELERATOR PHYSICS

The additional edge-focussing introduced by the 3T rectangular Superbend, together with the high vertical beta function at that point, $\beta_{ymax}$ ~ 24m, results in an increase of the vertical tune of ~0.04, and a vertical beta-beat of ~ ± 30%. There is also a change in vertical chromaticity of -0.7 and a small increase in emittance from the nominal 2.74 nm to 2.85 nm, which is deemed acceptable. In principle the vertical focusing effects could be overcome by employing a sector magnet geometry; the horizontal focusing so introduced would have a small effect on the horizontal optics because of the small horizontal beta function at the dipole. However, a rectangular magnet is preferred for simplicity of construction and so this case has been investigated. Following simulated global optics correction using LOCO [6], the vertical tune is restored to the nominal value with a beta variation of < 1%, apart from the horizontal beta in the Superbend itself. The required quadrupole changes are < 1% apart from the quadrupoles on either side of the Superbend, where changes of ~3% are required (see Fig. 5). Following correction, no significant effects have been seen on dynamic aperture, Touschek lifetime or injection efficiency. No difficulty is therefore expected in commissioning and operating with such a Superbend.

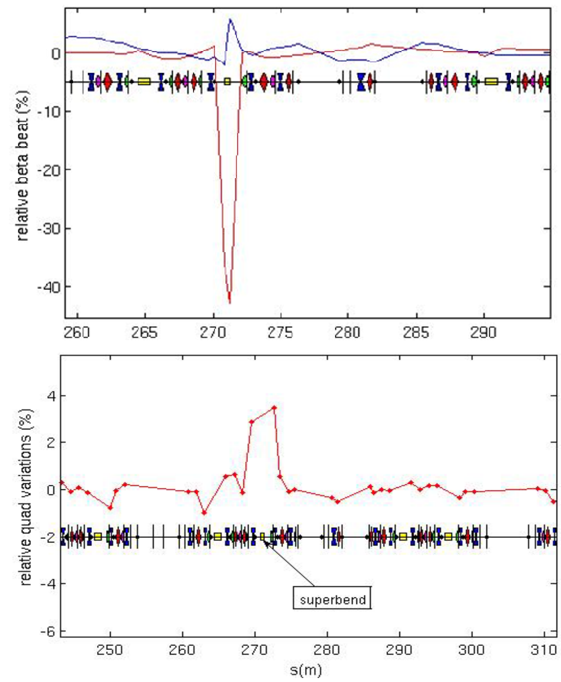



Figure 5: Upper - beta functions (red- horizontal, blue- vertical) relative to the unperturbed values in the vicinity of the Superbend after correction. Lower – required quadrupole changes for optics correction.

## CONCLUSION

Installation of a 3T Superbend in Diamond appears to be feasible. A new dipole/crotch vessel is needed with reduced apertures and improved crotch absorber to handle the higher heat load but appears to be feasible. No significant accelerator physics issues have been identified.

Should the requirement for a Superbend beamline proceed further, other options that may be considered to reduce power consumption and increase field at the radiation tangent point are a combined permanent magnet + electromagnetic design, or a superconducting magnet.

## REFERENCES

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