BENDING MAGNET PHOTON ABSORBER DESIGN AND CALCULATIONS FOR THE ELETTRA 2.0 STORAGE RING

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Abstract

To harness the major advances that have been done in the field of synchrotron light research, Elettra synchrotron radiation facility is being updated. Presently in its design phase, the Elettra 2.0 project will allow new and better research to be performed at the facility. In the upgrade of the storage ring, the new 6BA lattice brings challenges in terms of available space and radiated power. This paper presents the bending magnet photon absorber designed to cope with the new requirements. The absorber concept created for ESRF-EBS has been revised and re-engineered to make it suitable for the specific features of Elettra’s sources. To reduce the high-power densities induced by the short source-absorber distance, the one-jawed, toothed profile was obtained via a robust optimization, considering possible misalignments or beam miss-steering. Novelty of the approach is the absorber insertion in the vacuum chamber from the inside of the ring. Finally, presented are the thermo-mechanical and computational fluid dynamics simulations (ANSYS) performed to validate the design, comprehensive of a Monte-Carlo, ray-traced simulation to evaluate photon reflections (SYNRAD) and their effects.

INTRODUCTION

Elettra 2.0 is the project that aims at upgrading the Elettra synchrotron radiation facility to the 4th generation standards, with a complete overhaul of its storage ring. The new ring will be hosted in the same building of the former, keeping its circumference (259.2 m), but with a complete re-design of its lattice and sources, bringing to a reduction in emittance and an increase in coherence and brilliance. The new ring will be centered around a twelve-fold symmetric 6-bend achromat (S6BA), operating at the main energy of 2.4 GeV and 400 mA [1]. The new lattice, given the fixed available space, will increase the spatial device density, reducing all the distances from the sources. This paper presents the photon absorber design assigned to main B80 bending magnet (its characteristics are available in Table 1). In the following, the design geometry is described, along with the simulations (thermal, structural and reflection-evaluation) performed to validate it.

GEOMETRY OVERVIEW

The S6BA lattice applied in the Elettra available space creates a tight layout with short distances amongst devices and few operative spaces, with wide-spread challenges to its design. The main challenge regarding the photon absorbers is posed by the short source-absorber distance, the one-jawed, toothed profile was obtained via a robust optimization, considering possible misalignments or beam miss-steering. Novelty of the approach is the absorber insertion in the vacuum chamber from the inside of the ring. Finally, presented are the thermo-mechanical and computational fluid dynamics simulations (ANSYS) performed to validate the design, comprehensive of a Monte-Carlo, ray-traced simulation to evaluate photon reflections (SYNRAD) and their effects.

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Table 1: B80 Bending Magnet Characteristics

<table>
<thead>
<tr>
<th>B80 bending magnet</th>
<th>ρ [mm]</th>
<th>θ [°]</th>
<th>B [T]</th>
<th>Lm [m]</th>
<th>P [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. 1</td>
<td>7912</td>
<td>2.1</td>
<td>1.0111</td>
<td>0.29</td>
<td>0.865</td>
</tr>
<tr>
<td>S. 2</td>
<td>5480</td>
<td>2.3</td>
<td>1.4597</td>
<td>0.22</td>
<td>1.368</td>
</tr>
<tr>
<td>S. 3</td>
<td>7912</td>
<td>2.1</td>
<td>1.0111</td>
<td>0.29</td>
<td>0.865</td>
</tr>
</tbody>
</table>
misalignment, beam with $\pm 1^\circ$ angular misalignment and compositions of the angular and translational misalignment. The optimization algorithm objective was to minimize the stresses (first and third principal and shear) in all the configurations. The final design values for the absorber are shown in Table 2.

Table 2: Optimized Geometrical Parameters

<table>
<thead>
<tr>
<th>Geometrical Parameters</th>
<th>(\alpha)</th>
<th>(2\beta)</th>
<th>(r)</th>
<th>(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main surface pitch</td>
<td>8 deg</td>
<td>72 deg</td>
<td>0.92 mm</td>
<td>2.84 mm</td>
</tr>
</tbody>
</table>

The absorber will be entirely machined, without any brazing and with the UHV knife seal integrated as-well. Also, all the Elettra 2.0 absorbers will be made out of CuCr1Zr. The proposed geometry is designed to be inserted from the inner side of the storage ring. To be able to do so without interfering with the electron beam, the absorber features a cut-out in the shape of Elettra 2.0 vacuum chamber, to maintain continuity along the electron beam path. The absorber insertion from the inner portion allows for better sighting of the alignment fiduciaries, since it makes use of the presence of the pathways on the same side, giving ampler angles of vision to the laser tracker. To protect the downstream vacuum vessel from the incoming synchrotron radiation, the teethed part of the absorber protrudes for 2 mm in the electron beam portion of the design. The teeth are parallel to the electron beam trajectory after the dipole interaction, in order not to create thin structures next to the point of SPD maximum value, which is the closest to the electron beam. Cooling wise, the design dissipate heat through two cylindrical blind channels, situated below the absorber jaw. Having blind holes allow not to have any brazing in contact with the vacuum, eliminating the risk of a failure and vacuum contamination with the coolant.

**Reflected Photon Minimization**

In the proposed design, several features aims to reduce the amount of reflected photons reaching the vacuum vessel walls, with a lightweight approach. To reduce the photon reflections entering the electron beam channel, the tooth profile closest to the electron beam is cut in half [2], keeping the angled portion only towards the absorber body. To tackle the reflections due to the low \(\alpha\) angle, a secondary screw-on bent copper sheet is used. This add-on allows to keep the absorber main body manufacturability via wire electrical discharge machining (W-EDM, [4]), which should allow to highly limit the deviation of the real teeth profiles from the design ones. The copper sheet is angled at 45° to deflect eventual further reflections back down towards the absorber main body; its lightweight and open design helps with the pumping of the radiation-induced outgassing. Even though the surface contact between the absorber main body and the add-on is small, it is still sufficient to dissipate the small reflected power, as it is shown in the simulation paragraph.

The final absorber design, along with the add-on reflection protection can be seen in Fig. 2.

**COOLING CHANNEL AND CFD**

The geometry used for the cooling channel uses the overall design seen in [2, 5]: two \(\varnothing 8\) mm blind holes with each a concentric \(\varnothing 6\) mm outer diameter tube (1 mm thickness). The coolant inflow is through the outside annulus, with the outflow through the inner cannula. The gap between the inner tube end and the blind hole bottom is sized so that the area of passage at the tip is the same of the inner tube. A volumetric-flow of 0.044 L s\(^{-1}\) (equivalent to 2 m s\(^{-1}\) in the outer annulus) has been chosen. The smaller area of the inner tube leads to an increase in speed in the coolant return, but given the steel walls, no velocity-induced erosion problems are foreseen.

The inner tube is kept centered by means of an outer helix that acts both as a support and a turbulence promoter. The 20 mm helix pitch has been chosen to obtain the maximum heat transfer coefficient increase compared to the bare annulus, while keeping the pressure drop contained to less than 0.7 bar. The cooling channels will be fed in parallel by tubing coming from the girder distributor, with dedicated return valves and flowmeters to regulate and monitor the coolant flow.

The CFD simulations was performed using ANSYS FLUENT [6] with a coupled pressure-velocity solution scheme, using the \((K-\omega)\) SST model for the turbulence. Figure 3 shows the pressure obtained from the simulations, with a total pressure dropsettled at around 0.68 bar. The calculated heat transfer coefficient is instead shown in Fig. 4, with an average value of 28 kW m\(^{-2}\) K\(^{-1}\).

![Figure 3: Calculated pressure drop in the helical channel](image-url)
MECHANICAL MODEL

The SPD to determine the temperature distribution was obtained with ray-tracing simulation (using SYNRAD [7]). The applied thermal load on the absorbers teeth has a maximum of almost 78 W mm\(^{-2}\) and a total heat load of around 2 kW. By having the teeth oriented parallel to the exit electron trajectory, the half tooth partially shadows itself, exposing the straight electron channel cut-out at a lower incidence angle with an overall improvement to the SPD reduction factor. This shadowing moves the effective SPD peak to the radius connecting the half-tooth to its neighbour, thus closer to the cooling and with more bulk material to absorb the power.

The thermal and structural simulations were performed in ANSYS Mechanical [8]. To lean towards safety, a constant heat transfer coefficient of 20 kW m\(^{-2}\)K\(^{-1}\) was used in the calculation, obtaining a maximum temperature of 231 °C in nominal conditions (Fig. 5) and of 283 °C with the worst alignment conditions (+ 2 mm, +1°). Reporting the severest results across the tested configurations, the first principal stress \(\sigma_1\) maximum value is calculated at 160 MPa, while the maximum third principal stress \(\sigma_3\) was evaluated at 260 MPa (Fig. 6), both in agreement with the stress criteria (\(|\sigma_{max}| < 280\) MPa). Maximum shear \(\tau_{max}\) attested at 130 MPa at worst (in agreement with the requirement \(\tau_{max} < 140\) MPa).

Reflection and Reflection Shield Evaluation

Due to the low incidence angles the expected reflected power amount is not-negligible. The design reflection performance was estimated via SYNRAD. The simulation predicts that only 2.5% of the photons hitting the absorber are reflected back into the electron channel, mainly due to the grazing incidence on the vertical half tooth face. All other photons are successfully trapped.

To simulate the interface between the absorber bulk and the reflection shield, a thermal conductance of \(1 \times 10^{-3}\) W mm\(^{-2}\)K\(^{-1}\) was chosen [9]. The results show that the reflection shield reaches the maximum temperature of 141 °C while absorbing 56 W.

CONCLUSIONS

The proposed absorber is capable of handling with a compact design the high spatial power densities that are induced by the short dipole-absorber distances. The results are within the chosen validation criteria both stress and temperature wise, also taking into account loose positional and angular tolerances (±2 mm, ±1°). The design can successfully be inserted from the inner side of the storage ring, allowing for better sighting of the alignment surveys. The Monte-Carlo, ray-traced simulation shows that the lightweight reflection shield proposed is effective at capturing the reflected photons, protecting the vacuum chamber walls without overheating.

REFERENCES


