ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB340

DESIGN OF THE MAGNETIC SHIELDING FOR 166 MHz AND 500 MHz SUPERCONDUCTING RF CAVITIES AT HIGH ENERGY PHOTON SOURCE

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Abstract

Five 166 MHz quarter-wave β=1 superconducting cavities and two 500 MHz single-cell elliptical superconducting cavities have been designed for the storage ring of High Energy Photon Source (HEPS). It is necessary to shield magnetic field for superconducting cavities to reduce the residual surface resistance due to magnetic flux trapping during cavity cool down. The magnetic shielding for both 166 MHz and 500 MHz superconducting cavities have been designed. The residual magnetic field inside the cavities have been calculated by using Opera-3D simulation software. The geographic location of the cavity being installed at the HEPS site and the fringe field of the upstream magnet are considered. These are reported in this paper.

INTRODUCTION

High Energy Photon Source (HEPS), a 6 GeV 1.3 km ultralow-emittance storage ring light source, is under construction in Huairou, Beijing, China. The RF system of HEPS storage ring [1] consists of two kinds of superconducting (SC) cavities, namely 166 MHz HOM-damped quarter-wave $\beta = 1$ SRF cavities for main accelerating and 500 MHz KEK-B type single-cell elliptical SRF cavities as 3rd harmonic cavities [2].

As part of magnetic flux in the environment will be trapped in the wall of the SC cavity when transformed into a superconducting state and increase the residual surface resistance, it is necessary to deeply shield the magnetic fields outside the cavity, mainly the geomagnetic field and the residual field of some magnetic materials. In order to shield geomagnetic field to the north easily, the beam pipes of all SC cavities are approximately along the east-west direction, as shown in Fig. 1. According to the records from National Science & Technology Infrastructure of China, the annual means of geomagnetic field in Beijing is about 552 mGs and the declination is 8.2° west [3]. These data in Table 1 will be used in the following analyses.

166 MHz CAVITY MAGNETIC SHIELD

The magnetic shield of the 166 MHz cavity is inside the liquid helium vessel and close to the cavity wall to avoid the interference of peripheral components. Figure 2 shows the structure which is composed of three parts to facilitate manufacturing and installation. The wall thickness of the shield is 1.3 mm. The material is permalloy (1J79) which has a high permeability in a weak magnetic field. The permeability characteristics of 1J79 at liquid helium temperature was measured by Central Iron & Steel Research Institute [4], shown in Fig. 3.

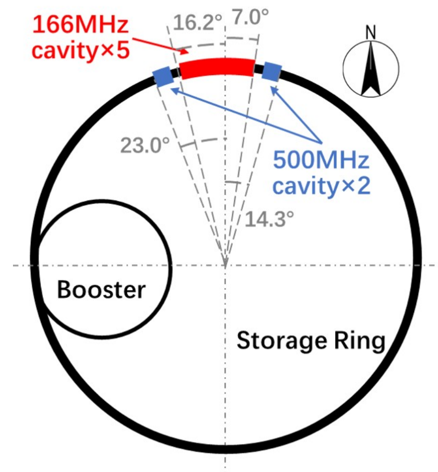

Figure 1: Locations of SC cavities in HEPS storage ring.

Table 1: Annual Means of Geomagnetic Elements in Beijing

Parameter	Value	Unit
X (North)	27920	nT
Y (East)	-4022	nT
Z (Vertical)	47494	nT
F (Total)	55239	nT
Declination	8.2 W	°

The shielding effect is evaluated using OPERA-3D and CST software. Considering the geomagnetic elements in Beijing as well as the position of the cavity, the worst case is selected for simulation, that is, the case where the cavity is on the easternmost side. The residual magnetic field on the cavity wall is shown in Fig. 4. It can be seen that the field near the large beam pipe port is strongest, which is the edge of the shield so there is a concentration of magnetic field. The remaining ports also have strong residual fields, but the fundamental mode magnetic field used for accelerating near all ports is weak and the power loss of residual resistance is small. While the residual field in the main body of the

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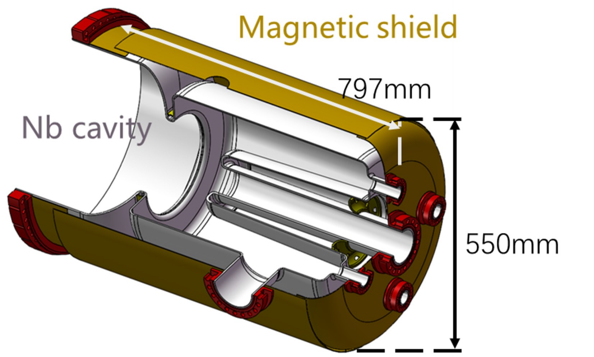

Figure 2: 166 MHz SC cavity magnetic shielding structure.

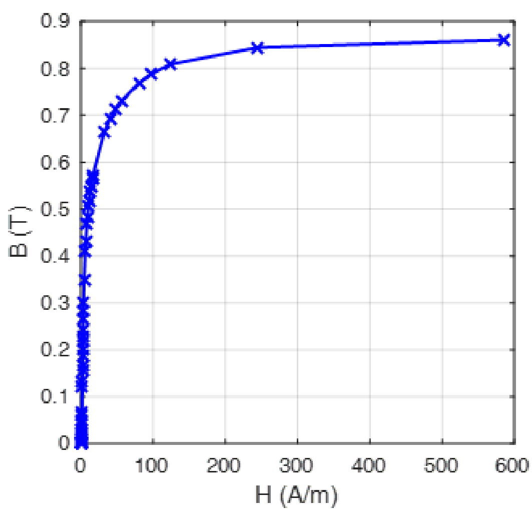

Figure 3: The B-H curve of 1J79 in liquid helium temperature.

cavity is weak, where the fundamental mode magnetic field is strong.

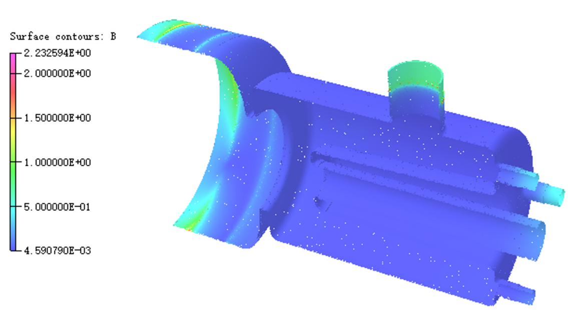

Figure 4: Residual magnetic field on the 166 MHz cavity wall (Unit: Gs).

The weighted average of residual resistance caused by trapped magnetic flux is calculated with the magnetic field distribution of the cavity fundamental mode according to the relation of external magnetic field, contribution to the residual resistance and the power loss shown in the flowchart Fig. 5 [5]. Final equivalent contribution for residual resistance caused by geomagnetic field is calculated to be $< R_{mag} >= 2.38$ nΩ and the equivalent residual magnet field on the cavity wall is $< B_{ext} >= 19.4$ mGs. $< R_{mag} >$ is less than the theoretical BCS resistance at 4.2 K of the 166 MHz cavity $R_{BCS}^{theory} = 10.7$ nΩ, meeting the design requirement of magnetic shielding.

$$B_{ext}$$

$$R_{mag} = 0.3(\mathrm{n}\Omega)H_{ext}(\mathrm{mOe})\sqrt{f(\mathrm{GHz})}$$

$$\left[P_{mag}\right]_n = \frac{1}{2} \times \left[R_{mag}\right]_n \times \left[\int |\boldsymbol{H}|^2 ds\right]_n$$

$$P_{mag} = \sum \left[P_{mag}\right]_n$$

$$\langle R_{mag} \rangle = 2 \times P_{mag} \div \oiint |\boldsymbol{H}|^2 ds$$

Figure 5: Calculate the equivalent residual resistance according to the external magnetic field.

Besides the geomagnetic field, there are magnets near the 166 MHz cavity modules. The center of the nearest magnet is 720 mm away from the flange face of the SC cavity. The local peak fringe field at the cavity module is about 400 mGs, which is close to the value of geomagnetic field. In order to explore the effect of magnet fringe field on shielding effect, we have carried out a simulation with the presence of both the geomagnetic field and the nearest magnet. Equivalent residual magnetic field and the contribution for residual resistance is calculated in the above same way. The corresponding $< B_{ext} >= 19.3$ mGs and $< R_{mag} >= 2.36$ nΩ. Fringe field of the magnet has little effect on the shielding results, probably because the fringe field and the geomagnetic field are in different directions and partly cancel each other out.

500 MHz CAVITY MAGNETIC SHIELD

In the 500 MHz cavity module, there is no structure specifically designed for magnetic shielding. The cylindrical cryostat of the module is made of pure iron (DT4) with high magnetic permeability, and has the function of magnetic shielding. The B-H curve of DT4 is shown in Fig. 6. The simplified shield model is shown in Fig. 7 and the outer wall thickness is 12 mm. Because the magnets are 2 m away from the 500 MHz cavity module, the fringe field of magnets is weak enough to be ignored. So the ambient field is only the geomagnetic field in the following simulation. In Fig. 1, compared to the cavity module on the west, the geomagnetic field component in the beam pipe direction of the east one is larger. Therefore, the east cavity is chosen as the object of simulation analysis.

The residual magnetic field on the 500 MHz cavity wall is shown in Fig. 8, which is more uniform and smaller than that on the 166 MHz cavity wall. The peak of the field is still at the beam pipe port, equal to 4.5 mGs. The residual

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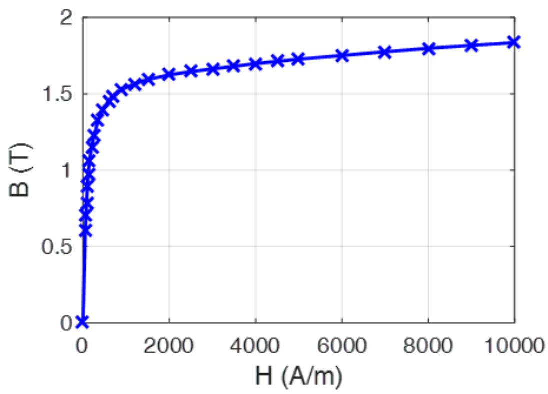

Figure 6: The B-H curve of DT4.

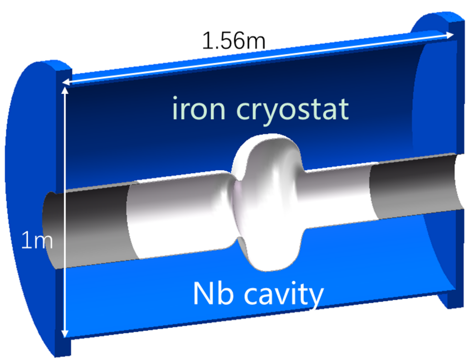

Figure 7: Simplified 500 MHz SC cavity magnetic shielding model.

resistance caused by trapped magnetic flux at 4.5 mGs is

$$R_{mag} = 0.3(\text{n}\Omega)B_{ext}(\text{mGs})\sqrt{f(\text{GHz})} = 0.95\ \text{n}\Omega. \quad (1)$$

Thus the equivalent residual resistance caused by geomagnetic field is no more than 0.95 nΩ, much less than the theoretical BCS resistance of the 500 MHz cavity at 4.2 K $R_{BCS}^{theory} = 7.9$ nΩ.

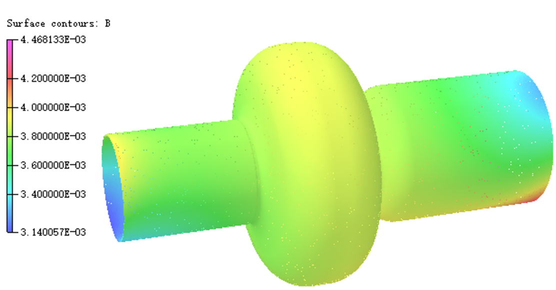

Figure 8: Residual magnetic field on the 500 MHz cavity wall (unit: Gs).

FINAL REMARKS

The magnetic shields of 166 MHz and 500 MHz SC cavities are evaluated using OPERA-3D and CST software. The equivalent contribution for residual resistance caused by the ambient fields are calculated and compared with the theoretical BCS resistances. Simulation results listed in Table 2 meet the design requirements.

Table 2: Results of Evaluation of 166 MHz and 500 MHz SC Cavitymagnetic Shields. "Magnets or Not" Stands for Whether the Fringe Magnetic Field of Nearby Magnets Is Considered

Parameter	166 MHz		500 MHz	Unit
Magnets or not	×	√	×	–
$< B_{res} >$	19.4	19.3	4.5	mGs
$< R_{mag} >$	2.38	2.36	0.95	nΩ
R_{BCS}^{theory}	10.7		7.9	nΩ

ACKNOWLEDGEMENTS

This work was supported in part by High Energy Photon Source, a major national science and technology infrastructure in China and in part by the Chinese Academy of Sciences.

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