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DESIGN AND SIMULATION OF 500 MHz SINGLE CELL SUPERCONDUCTING CAVITY*

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Abstract

The Shenzhen Industrial Synchrotron Radiation Light Source is a fourth-generation medium-energy light source with a 3GeV storage ring electron energy and an emittance less than 100 pm·rad. In order to ensure the long-term stable and efficient operation of the light source, a new type of 500 MHz single-cell superconducting cavity was designed in this study to be used as a pre-research superconducting cavity for the Light Source. The 500 MHz superconducting cavity has a large beam aperture and low high order modes (HOMs) impedance, which can be used in accelerators with larger currents. In this design, we simply adopted the same design scheme as the KEKB-type and CESR-type superconducting cavity. Using CST electromagnetic field simulation software to calculate and simulate the characteristics of the cavity, the results show that the designed 500 MHz single-cell cavity can meet the requirements of a high acceleration gradient, a high *r*/*Q* value, and a low peak surface field.

INTRODUCTION

With the development of superconducting radio frequency technology, the superconducting cavity has been proven to be the best solution for compact, high-power and high-current accelerators. The application of single-cell superconducting radio frequency cavities in synchrotron radiation sources has also been widely recognized. The 500 MHz single-cell superconducting cavity has been successfully applied to major synchrotron radiation sources in the world. The most representative one should be the CESR and KEKB 500 MHz single-cell superconducting cavities developed by Cornell University and KEK in the 1990s. The KEKB type superconducting cavity has a cylindrical large beam tube (LBP), which is designed to 1) propagate the high-order modes (HOMs) along the beam axis; 2) Damping the HOMs through the ferrite absorber pasted on the inner surface of the beam tube on both sides of the cavity [1]. The ferrite absorber damps the HOMs. The CESR cavity uses a fluted beam tube (FBT) to propagate HOMs. It has four special grooves that can reduce the cut-off frequency of the dipole mode and the round beam tube (RBT), and its cut-off frequency is high enough to exceed the resonance of the fundamental mode Frequency, but less than the resonant frequency of the HOMs of the second magnetic monopole [2].

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In addition, due to the large beam aperture of the superconducting cavity, the use of low-frequency resonant superconducting cavities in high current accelerators can suppress wake field effects and HOMs losses. Compared with a cavity that resonates at a higher frequency, a 500 MHz single-cell superconducting cavity has a lower surface resistance in the BCS theory [3]. The use of a low-frequency cavity can solve the challenge of low-temperature power loss of continuous wave high-current accelerators [4]. However, due to the large size of the low-frequency superconducting cavity, manufacturing and surface treatment will also bring another challenge [5]. What is exciting is that, through continuous in-depth research in recent years, Chinese researchers have realized the localization of all processes including the manufacturing and surface treatment of superconducting cavities. However, the prepared superconducting cavity type still belongs to the existing design cavity type abroad [6, 7]. Therefore, in order to realize the localization of superconducting cavities, an optimized state-owned superconducting cavity structure is proposed [8].

In this thesis, a new type of 500 MHz single cell superconducting cavity is proposed based on the development of the international 500 MHz single cell superconducting cavities in recent years. Through a large amount of simulation design and calculation, the spare superconducting cavity of Shenzhen Industrial Synchrotron Radiation Light Source was designed. This research provides the preliminary structure design and simulation calculation of various performance parameters. The optimization goals of this design include, for example, lower surface electromagnetic fields (E_p/E_{acc}, H_p/E_{acc}), lower low temperature loss, stronger HOMs damping, or lower loss factor. Some of these goals are mutually exclusive, so in the actual design, we have carried out comprehensive considerations to achieve the best results. The innovation of this design lies in the combination of the advantages of the two cavities, the LBT of KEKB and the FBT of CESR.

CAVITY DESIGN

The new superconducting cavity combines the FBT of the CESR cavity and the LBT of the KEKB cavity. Its obvious advantages are: large beam aperture, small beam loss, good electron acceleration, HOMs suppression and power transmission effects. A typical cavity shape is shown in Fig. 1, where l is the length of the cell, R_{eq} is the equatorial radius, R_{ir} is the iris radius, b_1/a_1 is the aspect ratio of the equatorial ellipse, and b_2/a_2 is the aspect ratio

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of the iris ellipse, d is the length of the straight line at the equator, and α is the angle of inclination. The straight line (d) at the equator helps to control the frequency and balance the flatness of the cavity field.

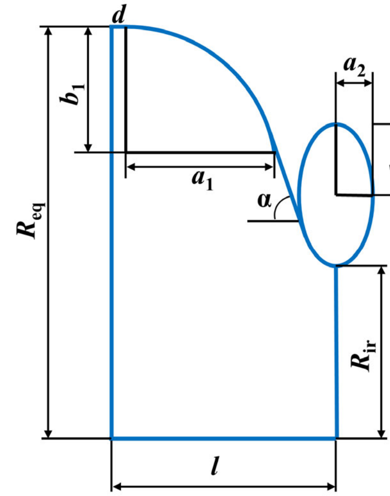

Figure 1: Geometric parameters of a typical cavity.

Cavity Equator Radius R_{eq}

With reference to the design parameters of the CESR cavity and KEKB cavity, we optimized a new type of 500 MHz superconducting cavity. Figure 2 shows the relationship between the performance parameters of the basement membrane and the cavity equatorial radius R_{eq}. It can be seen from the figure that the value of E_p/E_{acc} shows a trend of first decreasing and then increasing, the value of r/Q gradually decreases, while the value of H_p/E_{acc} basically does not change. In addition, the value of r/Q intersects the values of H_p/E_{acc} and E_p/E_{acc} when R_{eq}=269.0 mm. Considering the changes of parameter values, we choose R_{eq} of 269.0 mm as the best cavity equatorial radius.

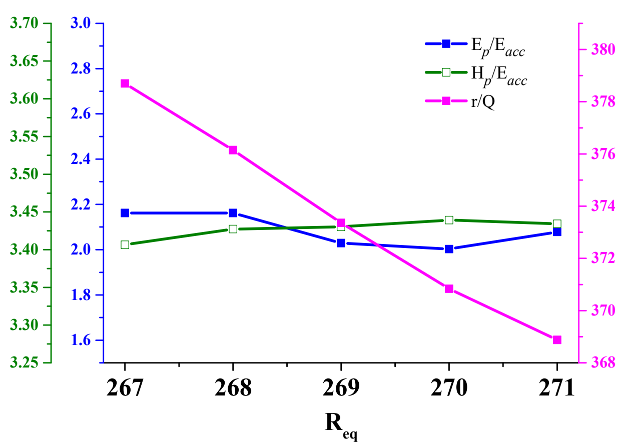

Figure 2: Variation curve of basement membrane performance parameters with cavity equatorial radius R_{eq}.

The Radius of the Ellipse at the Top of the Cavity R_top (a_1=b_1)

Figure 3 shows the relationship between the performance parameters of the base film and the top ellipse radius $R_{\_top}$ (a_1=b_1). The value of E_p/E_{acc} is the smallest when a_1=b_1=85 and 89 mm, the value of r/Q fluctuates, and the value of H_p/E_{acc} gradually decreases (Fig. 3). Considering the changes of parameter values, we choose a_1=b_1=89 mm as the best ellipse radius at the top of the cavity.

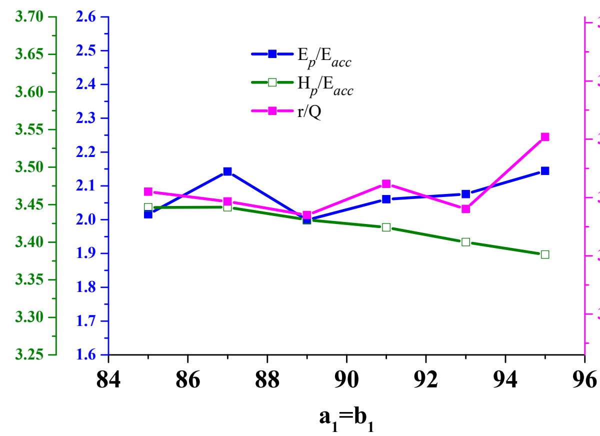

Figure 3: Variation curve of base film performance parameters with top ellipse radius $R_{\_top}$ (a_1=b_1).

The Radius of the Ellipse at Iris Changes (the Ellipticity does not Change)

Figure 4 shows the relationship between the performance parameters of the base film and the radius of the ellipse at the iris. The value of E_p/E_{acc} first increases and then decreases, the value of r/Q gradually decreases, and the value of H_p/E_{acc} fluctuates very little (Fig. 4). Considering the changes of parameter values, we choose a_2=20 mm as the best iris ellipse radius.

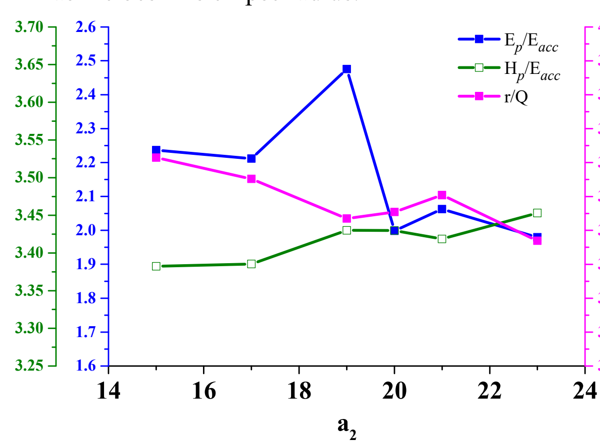

Figure 4: The curve of the performance parameters of the base film changing with the radius of the ellipse at the iris (the ellipticity does not change).

Iris Ellipse Radius Change (Ellipticity Change)

Figure 5 shows the relationship between the performance parameters of the base film and the radius of the iris ellipse (change in ellipticity). It can be seen that with the increase of b_2, the value of E_p/E_{acc} first decreases and then increases, the value of r/Q gradually increases, and the value of H_p/E_{acc} gradually decreases. Considering the changes of parameter values, we choose b_2=40 mm as the best iris ellipse radius.

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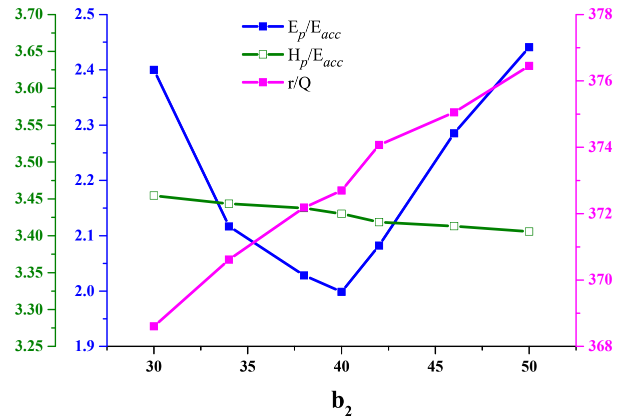

Figure 5: The relationship between the performance parameters of the base film and the radius of the iris ellipse (change in ellipticity).

New Superconducting Cavity Structure

Through a large number of simulation calculations, size optimization and result comparison. Through comprehensive consideration, the structure and performance parameters of the new type of 500 MHz single-cell superconducting cavity are shown in Table 1, and the relevant simulation diagram is shown in Fig. 6.

Table 1: The Structural Dimensions and Performance Parameters of the New Cavity

Parameters	**Value [mm]**
R_{ir}	120
RFBT	183
R_{eq}	269.0
l	120.04
a_1/b_1	89/89
a_2/b_2	20/40
d	4.9
$\alpha(°)$	80
Freq/MHz	499.98
$r/Q/\Omega$	372.70
G/Ω	247.0
E_p/E_{acc}(void)	2.00
H_p/E_{acc}(mT/(MV/m))	3.43

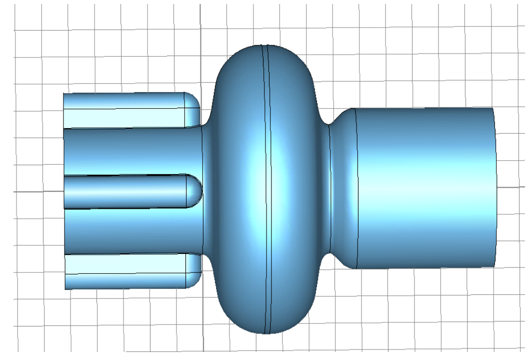

Figure 6: 3D structure model of the new superconducting cavity.

Structural Design of Beam Tube

Suppressing HOMs is one of the two most critical technologies for superconducting cavity design. A HOMs suppression method that has been successfully developed and applied is to use a larger beam tube diameter. Therefore, this study uses a beam tube diameter of 150 mm to elicit HOMs. The bundle tube parameters are shown in Table 2.

Table 2: Superconducting Cavity LBT Parameters

Parameters	**Value [mm]**
R_{ir}	120
R_{eq}	150
l	50
a_1/b_1	38/38
a_2/b_2	10/10

In addition, the design length of the beam tube is mainly set according to the attenuation of the fundamental mode TM_{010} in the cavity. In order to achieve an attenuation of about 50 dB, we take the length of the FBT at both ends of the cavity to be 260 mm, and the length of the large-aperture beam tube to be 300 mm. Figure 7 is the distribution curve of the electric field of the fundamental mode along the axial direction.

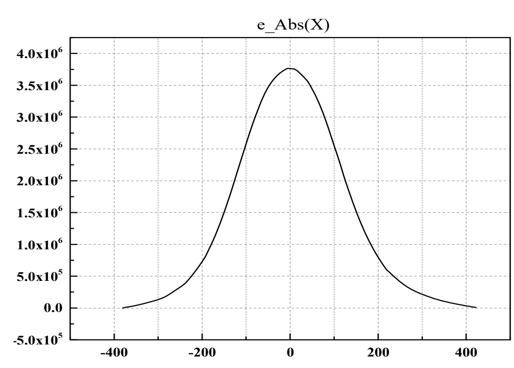

Figure 7: The distribution curve of the electric field of the fundamental mode along the axial direction.

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CONCLUSION

This design refers to two types of superconducting cavities, KEKB and CESR, which are the mature superconducting cavity types widely used in the world, and optimizes the cavity structure. The results show that the performance parameters of the new 500 MHz single cell superconducting cavity are significantly better than those of KEKB and CESR. This new cavity combines the advantages of CESR's FBT and KEKB's LBT. The new cavity type meets the fundamental mode frequency of 500 MHz, and other performance parameters, such as r/Q value, ratio of surface electromagnetic field to accelerating electric field (E_p/E_{acc}, H_p/E_{acc}), meet the design requirements. At this stage, this research is still in the cavity design stage. The next work is to design the high-power input coupler, and then carry out the electron Multipacting research. Finally, the superconducting cavity manufacturing, surface treatment, vertical testing and horizontal testing will be carried out.

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