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Studies on Higher Order Modes in BEPC Ⅱ Superconducting Cavity

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Abstract To investigate the higher order mode (HOM) damping in the BEPC Ⅱ superconducting cavity (SC) when using HOM absorbers, simulations have been done for changing the position and the length as well as the thickness of ferrite of HOM damper, and for different positions and angles of taper. The optimized values under which the HOM impedance of the BEPC Ⅱ SC cavity will be trapped in the impedance threshold of the BEPC Ⅱ collider have been found. For verifying the simulation result mentioned above, HOM measurements on the BEPC Ⅱ model cavity have been made, and the satisfied results for HOM damping are obtained. The distribution and magnitude of some potentially dangerous higher order modes have been found, which are basically consistent with the simulations.

Key words higher order modes, impedance, HOM damping, SC cavity

1 Introduction

As we know, Beijing Electron-Positron Collider (BEPC) has been operated over 15 years. For the strategy of high energy physics, it is experiencing an upgrade, namely BEPC Ⅱ which will be a double-ring high-luminosity colliding machine. As one of the most important parameters of collider, the luminosity of BEPC Ⅱ will reach $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ which is 100 times of BEPC. Based on the strategy of the luminosity upgrade from BEPC to BEPC Ⅱ, the optimized beam energy region and the beam current are designed as 1.89 GeV and 910mA with a beam length of about 1.5cm. The present BEPC RF system can not give a satisfied solution for the levels of the cavity voltage, the RF power, the HOM impedance and the operation frequency required by BEPC Ⅱ. For this reason, the old RF system must be replaced entirely by a new one. Considering BEPC Ⅱ's strict impedance limitation, and the maturity and the worldwide application of the superconducting RF technology, also as the strategic goal of developing accelerator technology in China, we will set up a superconducting RF system with a frequency of 500MHz in the BEPC Ⅱ project, instead of the existing 200MHz normal cavity system. The whole RF system includes two subsystems. Each subsystem is composed of one SC cavity, a 250kW power source system, a low level control system and local cryogenic equipment. For the lack of the technology and experience of SC cavity, we will benefit from the advanced SC RF system being operated in the world. Up to now, in the frequency range of 500MHz there are two machines, KEKB and CESRc, with the SC cavities experiencing the higher beam loading. For the similarity, the KEKB SC cavity can be as a reference in the BEPC Ⅱ cavity study and design.

In the preliminary BEPC Ⅱ RF design, we have made some cavity design based on the KEKB SC cavity shape, including decreasing the frequency from 508.8MHz to 499.8MHz to fit the requirement of BEPC Ⅱ and optimizing the cavity to minimize the HOM impedance to the threshold of multi-bunch instability.

2 Threshold of multi-bunch instability

From the accelerator physics requirement of BEPC Ⅱ, we should specially pay more attention to minimizing the impedance that may cause the single or coupled bunch

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instability. The limitation on the narrow band impedance comes from the coupled bunch instability. According to that the growth rate of the coupled bunch instability for equally spaced bunches should be less than the synchrotron radiation damping[1], the BEPC Ⅱ longitudinal impedance at any resonance frequency of the high order modes (HOMs)[2] should be

$$\frac{f}{\mathrm{GHz}}\,\frac{\mathrm{Re}\,Z}{\mathrm{k}\Omega}\,\mathrm{e}^{-(2\pi f\sigma_l/c)^2} < 0.49. \qquad (1)$$

Similarly, in the transverse case, the limitation of impedance[2] is

$$\frac{\mathrm{Re}\,Z}{\mathrm{k}\Omega/\mathrm{m}}\,\mathrm{e}^{-(2\pi f\sigma_l/c)^2} < 21.5. \qquad (2)$$

Eqs. (1) and (2) give an entire criterion to evaluate which HOM will be damped and the magnitude of the HOM impedance. For the BEPC Ⅱ case, the transverse impedance limit should not be tight by the theoretical estimation, the longitudinal impedance threshold is very critical, which should be highly considered in our concern.

Fig.1 shows the BEPC Ⅱ threshold of the HOM impedance at the frequency from 500MHz to 2300MHz.

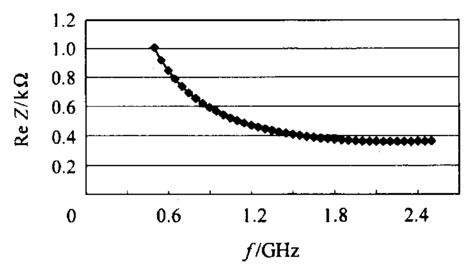

Fig.1. BEPC Ⅱ longitudinal threshold of the HOM impedance.

3 Simulations of the HOM damping for the BEPC Ⅱ SC cavity

As we know, RF cavity is the most dangerous source of the HOM impedance. So, how to highly damp the HOMs in BEPC Ⅱ SC cavities is a key issue. Considering the mature SC cavity technology in KEKB and the collaboration between KEK and IHEP, we will design the BEPC Ⅱ SC cavity based on the KEKB SC cavity design. First, a simple modification for the KEKB SC cavity, an extension of the cell length by 23.7mm at the cavity equator is made to fit the BEPC Ⅱ frequency of 499.8MHz (see Fig.2). As a result for this kind of cavity design, the HOM impedance exceeds the threshold mentioned above by simulations using CLANS code[3], so the HOM damping optimization needs to be made to satisfy the requirements of BEPC Ⅱ cavity impedance.

How to lower the HOM impedance of SC cavity with the optimized cell shape? For the BEPC Ⅱ SC cavity showed above, there are several possible ways. The optimizations of the HOM absorber and beam pipe tapers should be more effective. Since most of the HOMs will propagate into the large beam pipe (LBP) and absorbed by the ferrite absorber located at LBP, the length and location as well as thickness of the HOM absorber ferrite should be sensitive to the HOM impedance damping. The simulations for above have been made and the satisfied optimization results have been got. As an example, Figs.3

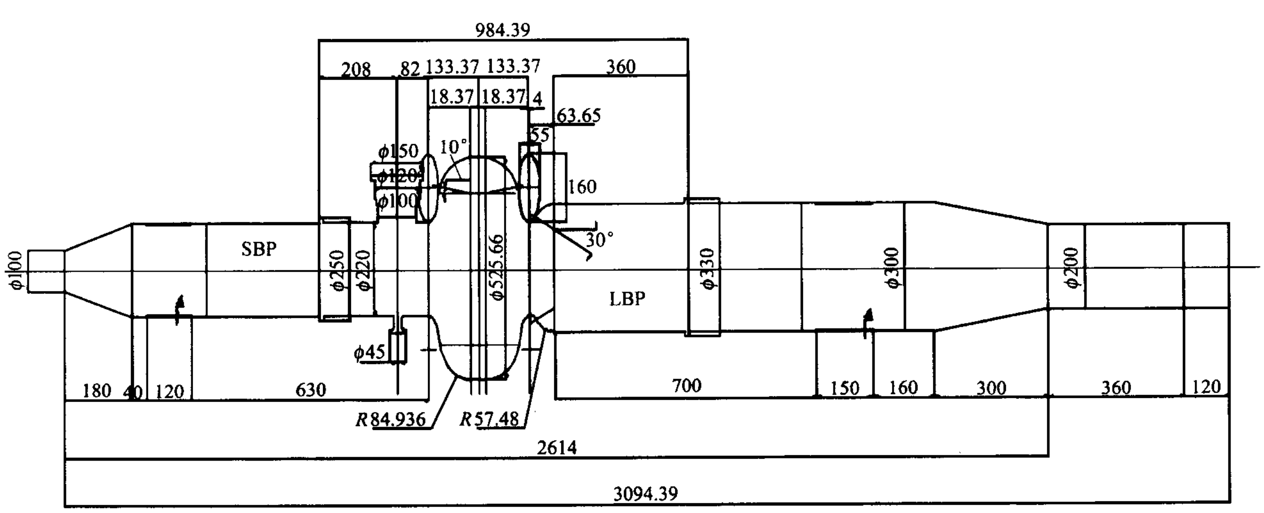

Fig.2. BEPC Ⅱ SC cavity shape (based on the KEKB SC cavity).

and 4 show the variations of impedance with the positions and lengths as well as thickness of the ferrite absorber in the LBP for TM011 mode, at the frequency of about 920MHz, which is the most dangerous among the HOMs of the BEPCⅡ SC cavity.

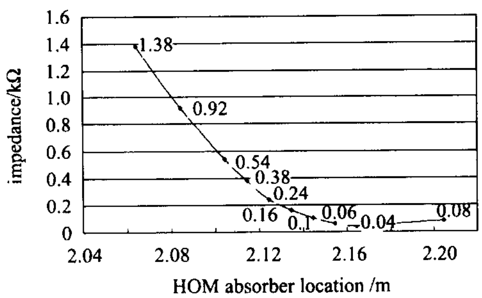

Fig.3. Impedance of TM011 vs. the location of the HOM absorber in the LBP (ferrite absorber length 0.15m).

In Fig.3, abscissa records the position of the ferrite absorber center from the left beginning of the whole cavity. In the simulation, the position of HOM absorber in the small beam pipe (SBP) need not be changed since TM011 mode nearly can not propagate out through the SBP. The sizes of both tapers are fixed as shown in Fig.2, and the ferrite thickness of 4mm is supposed.

Fig.4 shows that the ferrite thickness of 4mm is the best choice for the TM011 mode damping. Due to the importance of TM011 in the contribution of HOM impedance, it can be concluded that the ferrite with the thickness of 4mm should be most effective in the maximum absorption of the whole HOM power in the BEPCⅡ cavity.

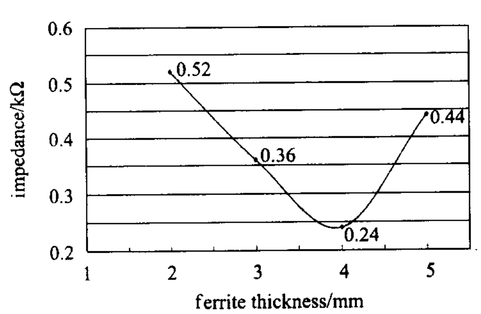

Fig.4. Impedance of TM011 vs. the ferrite thickness of the HOM absorber in the LBP (ferrite length: 0.15m).

The above simulation results show that HOM absorber in the LBP should be fixed at the location of about 2.16m from the left beginning of cavity, which is the point of the minimum impedance value for the most dangerous mode, TM011. From the simulation results of the other HOMs in cavity, this point is also the fitting point of the impedance damping for the whole HOMs spectrum below the cutoff frequency. At this position, the longitudinal impedance of all HOMs below cutoff frequency will be below the BEPCⅡ longitudinal threshold shown in Fig.1.

4 Experimental results of the HOM damping

To verify the simulation result of HOMs, the BEPCⅡ SC model cavity, modified from the KEKB model cavity, had been measured. On this model cavity without and with the HOM damper, we first measured the Q of HOMs one by one in the whole HOM spectrum. And, we changed the longitudinal position of the HOM damper to do the same measurements to get the information of HOM damping varying with different ferrite positions. The measurement results (Figs.5—7) show the Q values of most HOMs in the model cavity with HOM damper have been reduced below100, and the deeper damping has been obtained after making some changes for the position of HOM damper.

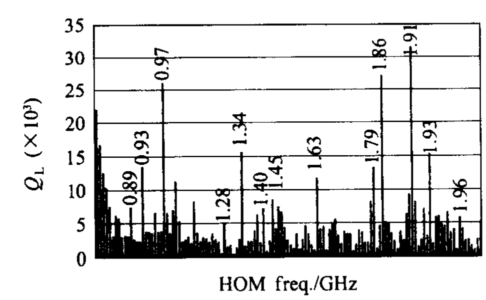

Fig.5. Measured loaded Q values of HOMs in the BEPCⅡ model cavity without HOM damper.

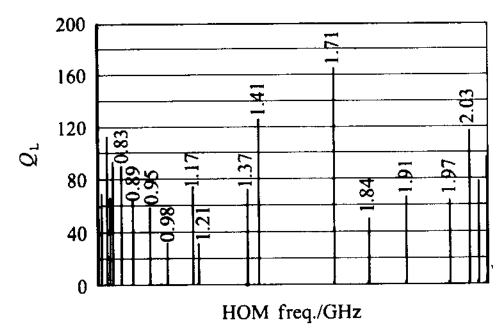

Fig.6. Measured loaded Q values of HOMs in the BEPCⅡ model cavity with HOM damper.

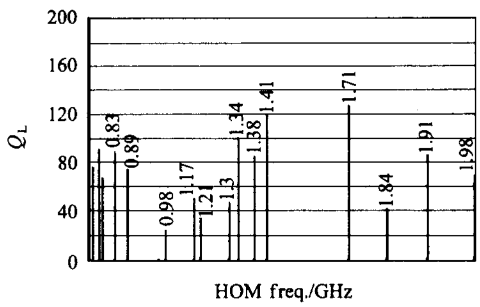

Fig.7. Measured loaded Q values of HOMs in the BEPCⅡ model cavity with HOM damper (change of 60mm of LBP HOM damper position toward cavity cell).

5 Conclusion

The simulations for the HOM impedance in BEPCⅡ SC cavity provide such information that the HOM impedance of the BEPCⅡ SC cavity can be damped below the threshold given by the beam instability study (Fig.1) through optimizing the position and the length of the HOM damper as well as the thickness of ferrite of the HOM damper. The measurement results for the BEPCⅡ model cavity show that the Q values of most HOMs can be greatly lowered under the installation of the HOM damper, which is generally consistent with the simulation result, and with the adjustment of the position of the HOM damper toward the cavity center the Q values would be lower. So, considering the results of simulations and the model cavity measurements, we may get a balance between the requirement of BEPCⅡ beam stability and the technical realization, which is 30mm drawing HOM damper on LBP back to cavity center.

References

1 Takaaki Furuya. Superconducting Cavity, Physics and Engineering of High-Performance Electron Storage Rings and Application of Superconducting Technology. Proceedings of the Asian Accelerator School, 1999

2 Impedance and Collective Effects, BEPCⅡ Design report, IHEP-AC-Report/2002-01, May 2002

3 CLANS Manual, Private Communication

BEPCⅡ超导腔高次模阻抗抑制优化研究

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摘要 BEPCⅡ 500MHz超导腔是BEPCⅡ储存环的关键设备,腔中高次模的分布和阻抗将很大程度上直接影响束流的稳定.因此,研究BEPCⅡ超导腔的高次模分布和高次模吸收器的吸收效果对实现BEPCⅡ指标至关重要.为此,通过改变高次模吸收器的位置、铁氧体吸收材料的长度、厚度以及腔的渐变过渡波导的角度等对BEPCⅡ超导腔高次模阻抗抑制进行了模拟优化研究,从而找到并确定了吸收器对高次模阻抗抑制的最优值.同时,为证实模拟计算结果的正确性,对BEPCⅡ超导模型腔进行了高次模分布和吸收测量,得到了与计算一致的结果.结果表明,经过细致优化腔的高次模吸收器,腔中大部分高次模被深度吸收了,那些具有潜在危险的高次模阻抗值降到了阈值以下,满足BEPCⅡ束流阻抗要求.

关键词 高次模 阻抗 阻抗抑制 超导腔

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