

THE DEVELOPMENT OF TE-SAMPLE HOST CAVITY AT IMP*

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Abstract

As a part of the research and development work of thin-film materials for superconducting radio frequency(SRF) application in future accelerator projects at Institute of Modern Physics, CAS, such as Heavy Ion Accelerator Facility(HIAF) and the SRF proton Linac for Chinese Accelerator Driven System etc., a 3.9GHz sample host cavity is being developed for the purpose of characterizing the RF property and the loss mechanism of the superconducting thin-film materials (e.g., Nb/Cu, Nb3Sn and MgB2 etc.). The cavity operates in the TE011 mode and accommodates disk sample with 110mm diameter, theoretically, the maximum magnetic field on sample surface can go up to 100mT, the resolution of surface resistance on sample can reach nOhm scale by using thermometry technique(T-Mapping). In this paper, the electromagnetic optimization result of TE-sample host cavity will be presented, and the design consideration of coupler and T-mapping system are also discussed.

INTRODUCTION

SRF technology has long been adopted in many particle accelerators world-wide in the past, such as Continuous Electron Beam Accelerator Facility(CEBAF) at Jefferson Lab and Spallation Neutron Source(SNS) at Oak Ridge National Lab, will be also used in future accelerator projects, such as FRIB at MSU, LCLS-II at SLAC, ESS and XFEL in Europe, Heavy Ion Accelerator Facility (HIAF) and the proton Linac for Chinese Accelerator Driven System at IMP, CAS, Light Source at IHEP, CAS, FEL at SINAP, CAS etc.. The key components in SRF accelerators are SRF cavities, which have been routinely fabricated by Niobium material. The performance of SRF cavity made out of niobium is mainly determined by the superheating magnetic field Hsh of niobium material ($H_{sh} \sim 240\text{mT}$ ($T=0\text{K}$)). After more than half a century development in SRF science and technology (the optimization of cavity structure and the advance in cavity surface processing techniques etc.) [1]. For the high beta cavities ($\beta=v/c$, v : the velocity of beam, c : the speed of light), its performance is approaching its material limit (Corresponding accelerating gradient $E_{acc} \sim 60\text{MV/m}$) [2]. However, the performance of low beta (0.01-0.3) cavities is still below its material limit, which is mainly determined by electron-loading effect inside the cavities (e.g., field emission effect and multipacting effect etc.) [1], and the cost of niobium bulk technique is still expensive.

In order to further reduce the total cost of the SRF cavities system in accelerator (i.e., the cost of SRF cavities and the cryogenic plant) and/or improve the accelerating field of the SRF cavities. One of the solutions is to use superconducting materials thin film technology for the fabrication of the cavity. Niobium thin film on copper substrate technology is attractive due to the high thermal conductivity of copper substrate. Other materials such as MgB2 and Nb3Sn etc. have great potential because of their higher critical temperature and superheating field (i.e. for MgB2: $T_c=40\text{K}$, $H_{sh}=430\text{mT}$ ($T=0\text{K}$); for Nb3Sn: $T_c=18.3\text{K}$, $H_{sh}=540\text{mT}$ ($T=0\text{K}$)) [3,4]. Many laboratory around the world are developing thin film technology for accelerator application.

At IMP, Our accelerator projects, HIAF and CIADS proton Linac both will use SRF technology as mentioned above. Therefore, we started our thin film study two year ago. Both niobium thin film on copper substrate and Nb3Sn on niobium substrate technology are being developed. Normally, the RF properties of thin film can be obtained by low temperature testing of the cavity coated with material thin film. But the results are averaged over the whole cavity surface, local loss mechanism cannot be precisely characterized. And coating the cavity with material thin film is complex and time-consuming. Another way to measure the RF properties of material thin film is to test the thin film sample, where the sample is set as part of the host cavity. To date, there are two methods to characterize the sample, i, end-plate replacement method; ii, RF-DC calorimetric method; the details of above methods are described in reference [5,6]. The measurement apparatus of method two is much complex in comparison with that of method one, because it needs to thermal decouple between host cavity and sample. In order to make host cavity structure simpler and easy to attach sample, reduce the testing period of each sample. Therefore we adopted the end-plate replacement method for the characterization of sample, the sample host cavity will operating in TE011 mode, For perfect TE011 mode, there will be no electric field perpendicular to cavity surface, to ease the electric related effect, such as multipacting and field emission effect. And no RF current cross the joints between host cavity and sample disk, to obtain high resolution of RF surface resistance.

In this paper, the electromagnetic optimization of the TE- sample host cavity will be presented, and the design consideration of coupler and T-mapping system will also be discussed.

CAVITY DESIGN

In the end-plate replacement methods, the host cavity resonates in the TE0mn mode, where the sample is one of the end-plates of the host cavity. By measuring the un-

* Work supported by National Natural Science Foundation for Young Scientists of China (Grant NO. 11505255).

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loaded quality factor Q_0 of the sample host cavity with reference sample and with the sample under investigation respectively. The RF surface resistance of the sample can be deduced from the difference in Q_0 .

Since the diameter of the sample is inversely proportional to the frequency of the host cavity. The surface resistance is proportional to square of the frequency. The thermal feedback analysis from Cornell university shows that the breakdown magnetic field of niobium cavity with thickness of 3mm are 60mT at frequency of 6GHz, and above 120mT at a frequency of 4GHz [5,7].

The optimization goal of our host cavity is as following:

- 1) TE011 mode operation, the frequency is less than 4GHz;
- 2) Sample size: the diameter is 110mm, with about 86mm diameter area of sample exposed to magnetic field;
- 3) Maximize the ratio of peak surface magnetic field on sample ($H_{pk,sample}$) over peak surface magnetic field on the host cavity wall ($H_{pk,wall}$).
- 4) Maximize G_{sample}/G_{cavity} , G_{sample} is the geometric factor of the sample plate and G_{cavity} is the geometric factor of the host cavity.

The electromagnetic optimization of the sample host cavity was performed by CST Microwave Studio. We started our optimization from the two geometric structures shown in Fig.1, one with cone part and the other one with Sphere part. Each structure parameterized by corresponding geometric parameters. All the parameters were swept in CST Microwave Studio, the optimal geometric parameters were obtained to meet our optimization goal of the host cavity.

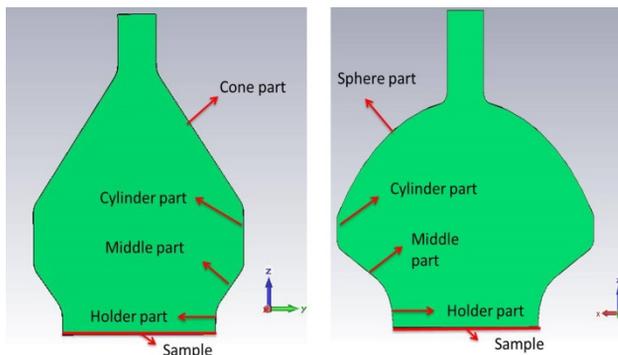


Figure 1: The geometric structures where we started our EM optimization. With cone part (left) and with sphere part (right).

Table 1 gives the optimization result of the sample host cavity. The ratio of peak surface magnetic field on sample surface over the peak surface on the host cavity is 0.85. According to the thermal feedback analysis [5,7], the maximum magnetic field on the sample surface can reach above 100mT. Fig.2 displays the distribution of the absolute value of electric field (top) and magnetic field (bottom) on the symmetric plane. As one can see, the electric field

on cavity surface does go to zero, and the magnetic field at the joints between sample disk and host cavity is approaching to zero. Therefore, the electron-loading effects can be avoided inside the cavity theoretically. The surface preparation will be much easier compared to that of the SRF cavity used in accelerators.

Table 1: The Optimization Result of the Sample Host Cavity

Parameters	Value
Frequency[GHz]	3.9
Sample Diameter(mm)	110
$H_{pk,sample}/H_{pk,wall}$	0.906

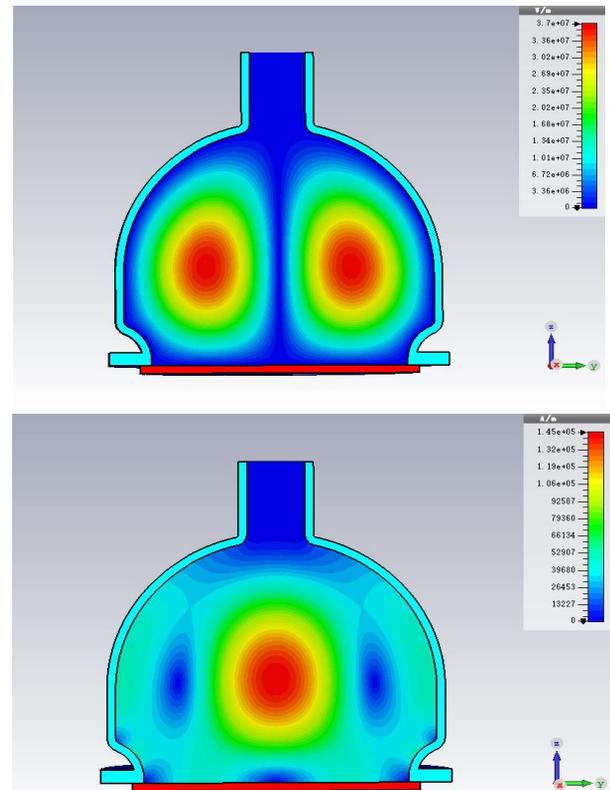


Figure 2: The distribution of absolute value of electric field (top) and magnetic field (bottom) on the symmetric plane.

COUPLER DESIGN CONSIDERATION

As mentioned before, our sample host cavity will be used to characterize both niobium thin film coated on copper substrate and Nb₃Sn thin film coated on niobium substrate. Therefore the variable coupler should be designed to test different samples with different RF surface resistance. The external quality factor of the coupler should be in the range of 1E7 to 1E10. The off-center hook coupler described in reference [5] will be considered for our sample host cavity.

T-MAPPING SYSTEM

The back-side of the sample surface will be attached with high-resolution temperature sensors. As a first step, ten five-silicon diode sensors were procured and will be set on two

concentric rings, and the corresponding Labview program is being developed.

CONCLUSION

Presently, both the niobium thin film coated on copper substrate and Nb₃Sn thin film coated on niobium substrate techniques is being developed at Institute of Modern Physics, CAS. As a part of the development of above techniques, we started to develop a sample host cavity operating in TE₀₁₁ mode and by using end-plate replacement methods combined with the thermometry system. To date, the electromagnetic optimization has been performed. The sample host cavity has a frequency of 3.9 GHz and characterize the sample disk with a diameter of 110mm. Theoretically, the peak magnetic field on sample surface can reach above 100mT. The sample will be attached with high resolution temperature sensors, and the variable coupler will be further optimized.

ACKNOWLEDGEMENTS

This work was supported by National Natural Science Foundation for Young Scientists of China (Grant NO. 11505255).

REFERENCES

- [1] Hasan Padamsee, Jens Knobloch, and Tom Hays, RF Superconductivity for Accelerators.
- [2] R. L. Geng, G. V. Eremeev, H. Padamsee, "High Gradient Studies for ILC with Single Cell Re-entrant Shape and Elliptical Shape Cavities made of Fine-grain and Large-grain Niobium", in *Proc. PAC'07*, Albuquerque, New Mexico, USA, paper WEPMS006, pp. 2337-2339.
- [3] S. Posen, "Understanding and overcoming limitation mechanisms in Nb₃Sn superconducting RF cavities", PhD thesis, Cornell University, 2015.
- [4] T. Tajima *et al.*, "Studies on superconducting thin films for SRF applications", in *Proc. LINAC'10*, Tsukuba, Japan, Sep. 2010, paper THP042, pp. 854-856.
- [5] Yi Xie, "Development of Superconducting RF Sample Host Cavities and Study of Pit-Induced Cavity Quench", PhD thesis, Cornell University, 2013.
- [6] Tobias Junginger, "Investigations of the surface resistance of superconducting materials", PhD thesis, the Ruperto-Carola University of Heidelberg, 2012.
- [7] D.L. Hall, M. Liepe, I. Madjarov, Y. K. McDermott, N. Valles, "Development and Performance of a High Field TE-mode Sample Host Cavity", in *Proc. SRF'13*, Paris, France, paper THP038, pp. 985-987.