DESIGN OF A TE-TYPE CAVITY FOR TESTING SUPERCONDUCTING MATERIAL SAMPLES[*]

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Abstract

To further the understanding of the r.f. performance of niobium and alternative superconducting materials such as MgB_2, high magnetic field tests of material samples inserted into host microwave cavities are potentially highly beneficial. In this paper we present results from a detailed design study of such superconducting sample host cavities. The focus of the design work has been on maximizing the ratio of sample surface magnetic field to host cavity maximum surface field, on multiple mode operation to study frequency dependent effects, on mechanical stability of the host cavity under atmospheric pressure, and on joints between the sample plates and the host cavity.

INTRODUCTION

Superconducting cavities operating in TE modes have long been used in characterizing superconducting material samples such as niobium, cuprate conductors and most recently MgB_2 [1]. This type of cavities typically consist of a host cavity and one or two detachable sample plates or just a material sample being placed on top of a position adjustable sapphire rod. TE monopole modes are especially favored because there are no surface electric fields on the sample plate thus enabling easier cleaning and preparation procedures. Also there are no surface currents flowing at joints between the host cavity and sample plates. Therefore ideally there will be no loss at the joints. Figure 1 shows the existing Cornell 6GHz niobium pill-box shape cavity operating in the TE_{011} mode which was used for example to characterize niobium films deposited on copper plates via the ultra-high vacuum cathodic arc (UHVCA) deposition method. Currently, the existing Cornell TE cavity can only reach a maximum magnetic field of 450Oe on the sample plate. The host cavity baseline Q factor is 3.5×10^8 as shown in Figure 2 due to large residual losses and coupler losses. The field ratio R, defined as

$$R = H_{max,sample}/H_{max,cavity} \qquad (1)$$

is lower than 1 for this pill-box cavity, which means that not the sample plate but the host cavity will reach maximum magnetic field first. In order to fully characterize the RF performance of Nb_3Sn and MgB_2, it is essential to achieve surface magnetic fields on material samples above 2000Oe. Thus only a new host niobium TE cavity shape with a higher intrinsic field ratio $R > 1$ can achieve magnetic fields on the sample above the RF critical field of niobium.

Figure 1: Existing pill-box shape TE cavity at Cornell.

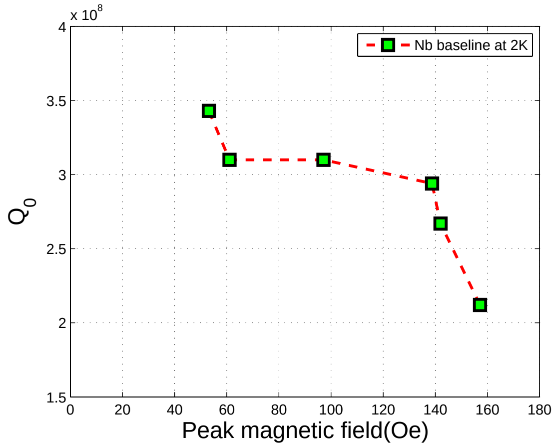

Figure 2: Baseline test of the existing TE cavity at Cornell for a baseline niobium bottom plate.

TE CAVITY DESIGN

The maximum magnetic field that can be achieved on the sample is limited by the breakdown magnetic field of the host cavity. Therefore, the main design goal is to maximize the ratio R of maximum sample plate surface magnetic field to maximum host cavity surface magnetic field.

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Other design constraints of the TE cavity are

- Sample size (bottom plate of the cavity) should be small (≤ 4 inches diameter).
- Lower excited modes frequencies (≤ 4GHz) are desirable to avoid global thermal instability as $R_{bcs} \propto f^2$.
- The cavity configuration should be relatively simple and the bottom sample plate should be easily to attach.

We started from several possible basic shapes that were evolved from the pill-box shape [2]. Each shape can be defined by a parameter set (a_1,a_2,...,a_n). Matlab scripts were used to generate geometry input files used by CLANS/SLANS [3] for a given parameter set. A modified version of CLANS was used to calculate EM eigenmodes and generated a file containing surface fields of calculated modes for each geometry. The surface field ratios R were calculated from the surface fields. Each parameter in the parameter set was modified by a centain step size and the ratio R was obtained for each variation. The iteration process was repeated until the best ratio was found. Since this optimization method was basically a gradient ascent search algorithm, the previous best result was re-optimized by the MATLAB optimizer *Fminsearch*$^{@}$ which uses the simplex search method [4].

IMPROVED HOST CAVITY SHAPES

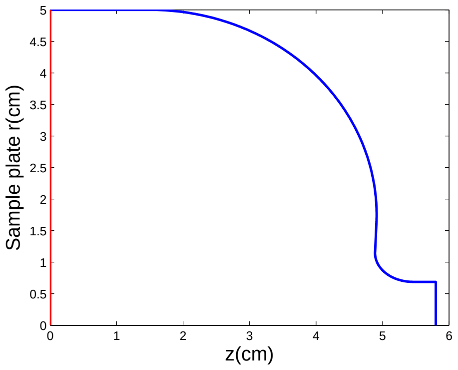
Three host cavity shapes have been obtained as shown in Figure 3. Two of them are excited in monopole mode as stated before. In a third design a dipole TE mode is explored because of its attractive high sample to cavity surface magnetic field ratio R. The design parameters of three shapes are summarized in Table 1. Note that the size of the sample plate can be readily scaled inversely proportional to the host cavity operating frequency.

Table 1: The design parameters of three types of TE cavities

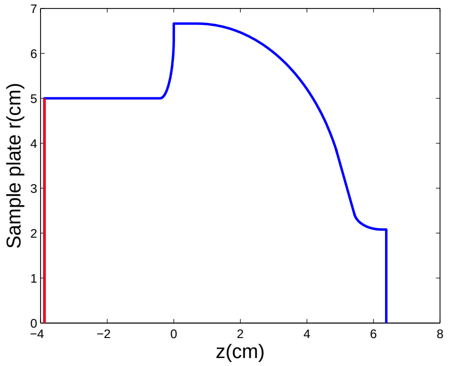
	TE_{011} mode	TE_{012} and TE_{013} mode	TE dipole mode
Ratio R	1.40	1.24(TE_{012}) 1.57(TE_{013})	3.25
f(GHz)	5.02	4.78(TE_{012}) 6.16(TE_{013})	4.01
Sample diameter(cm)	10.0	10.0	10.0

MECHANICAL ASPECTS

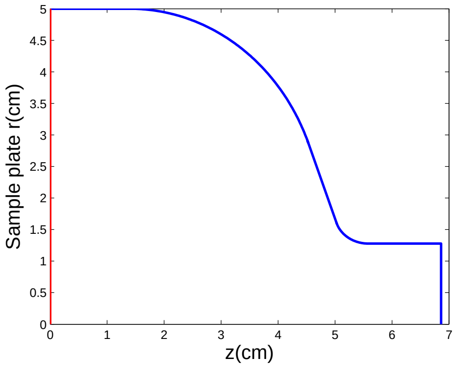
In order to study the deformation of the host cavity and sample plate when the cavity is under vacuum and the outside at atomosphere pressure, stress analysis was performed using Inventor$^{@}$ for all three types of host cavities [5]. The most serious deformation is located at the center of the sample plate for every design. Figure 4 shows deformation calculations under 1 atm outside. The scaling law is that the maximum deformation is approximately proportional to the diameter of sample plates. The largest deformation is about 0.15mm for a 10cm diameter niobium sample plate of 3mm thickness which is acceptable. Sample plates with diameters above 15cm become unfeasible because of the high stress and strains if the cavity is evacuated.



(a) Design A

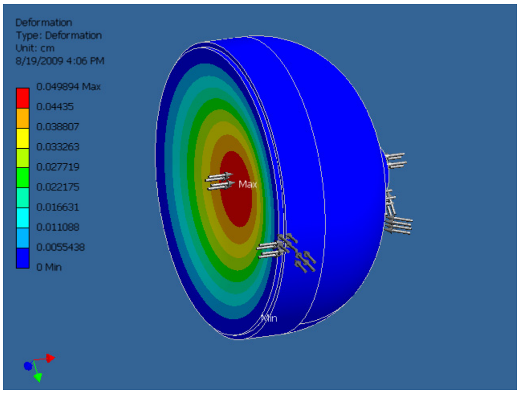


(b) Design B

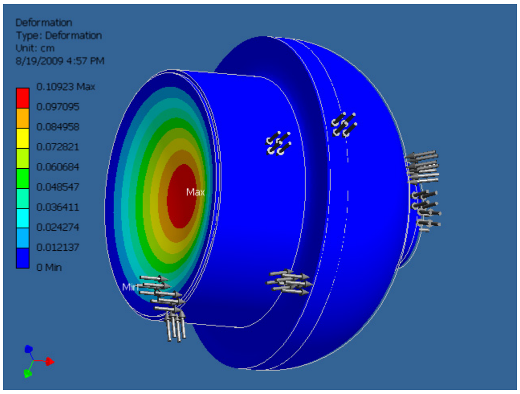


(c) Design C

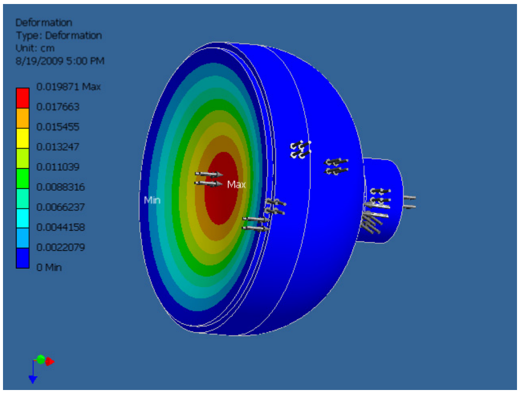
Figure 3: Three shapes of host cavity (blue) and sample plate (red).



(a) Design A



(b) Design B



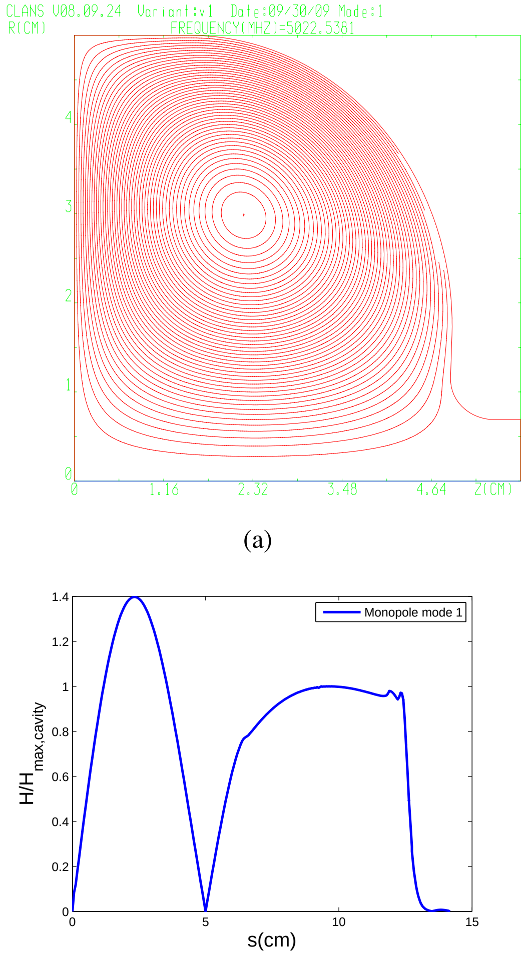
(c) Design C

Figure 4: Deformation calculations for the case that the host cavites are under vacuum and the outside at atomosphere pressure.

ELECTROMAGNETIC ASPECTS

Design A: Operating in TE_{011} Mode

Figure 5a shows the magnetic field lines distribution for the first type of a TE cavity excited in TE_{011} mode. The cavity is of slightly reentrant shape. The surface magnetic field along the entire cavity cover and sample plate is displayed in figure 5b. The surface field ratio R is 1.4 which indicates that 2800Oe can be reached theoretically on material samples assuming a niobium superheating field $H_{sh} = 2000$Oe for the niobium host cavity [6].



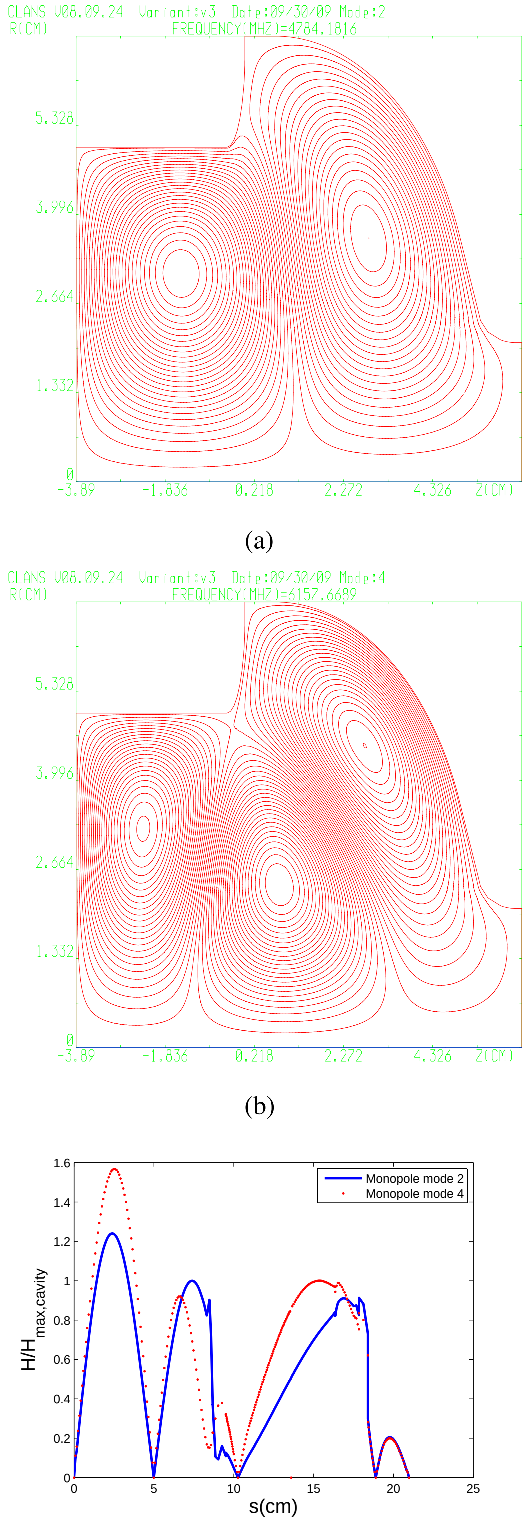
(a)

(b)

Figure 5: Magnetic field lines distribution (a) and normalized surface magnetic field distribution (b) of design A. The sample plate (s=0 to 5 cm) and walls of the host cavity (s=5 to 14 cm).

Design B: Operating in TE_{012} and TE_{013} Mode

The novel feature of this cavity design is that it allows to test material samples under two different frequencies. The maximum of the surface magnetic field on the sample plate is at the same location for both modes as seen in figure 6c. This beneficial feature enables us to determine the frequency dependence of the rf performance of sample materials without changing the host cavity. Figure 6a and Figure 6b shows the magnetic field lines distribution for both TE_{012} mode and TE_{013} mode. The surface field ratio R for TE_{012} mode is 1.24 which suggests that surface magnetic field on material samples can reach 2480Oe. The surface magnetic field on material samples can even reach up to 3140Oe for the TE_{013} mode with a field ratio $R = 1.57$.

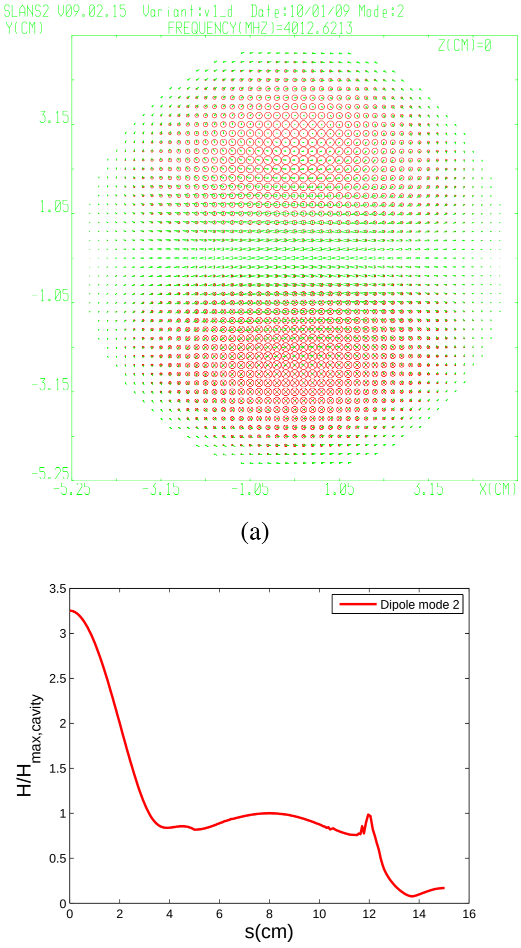


(a)

(b)

(c)

Figure 6: Magnetic field lines distribution for a TE_{012} mode (a) and a TE_{013} mode (b). (c) is the normalized surface magnetic field along the sample plate (s=0 to 5 cm) and walls of the host cavity (s=5 to 21 cm) of design B.



(a)

(b)

Figure 7: Surface magnetic (green) and electric (red) field distribution (a) on the sample plate for a TE dipole mode design C. (b) is the normalized surface magnetic field along the sample plate (s=0 to 5 cm) and walls of the host cavity (s=5 to 15 cm).

Design C: Operating in TE Dipole Mode

The TE dipole mode host niobium cavity design has the highest surface field ratio $R = 3.25$ which means that the surface magnetic field on sample plates can reach 6500Oe theoretically. The maximum of the surface magnetic field is located at the center of the sample plate as shown in figure 7b. Figure 7a shows the surface electric and magnetic field distribution at the sample plate. Due to the presence of surface electric fields, carefully cleaning and preparation of the host cavity is essential to avoid possible multipacting and field emission.

JOINTS

Since surface magnetic fields at the edge of sample plates for the TE monopole mode A and B go to zero, as shown in figure 5b and 6c, there should not be any loss at the joints ideally. In the presence of finite size joints, our calculations show that small surface magnetic fields leaking into the joint region outside the sample plates decay expoenentially in the radial direction. Therefore very low loss joints between host cavities and sample plates can be achieved for the TE monopole mode designs A and B. However, the seal problem is pronounced for the TE dipole mode design C because the surface magnetic field at the edge of the sample plate does not go to zero as shown in figure 7b. Thus a choke joint needs to be designed to decrease the surface magnetic field at the joint and to enable low loss at the possible indium seal.

CONCLUSION AND OUTLOOK

We have obtained three cavity shapes that would lead to high surface magnetic field at the sample plates with relatively simple host cavity shapes. Surface magnetic field on material samples could reach 2800Oe theoretically in the TE monopole single mode design A. The TE monopole double mode design B enables two mode measurements of the test material samples to study frequency dependence of the surface resistance. The highest surface magnetic fields that could be achieved on samples are 2480Oe and 3140Oe. For the TE dipole mode design C, maximum surface magnetic field could reach 6500Oe. However for this design C, since the surface magnetic field does not go to zero at the edge of the sample plate and since surface electric fields are present in the host cavity, the possibility of multipacting needs to be fully considered. In addition possible designs of the input and pickup antenna couplers inserted at the cavity top plate will be addressed in the future. After finishing the design, we plan to build the hostcavites at the end of this year, with rf test starting next year.

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