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DESIGN STUDY OF MUSHROOM SHAPED CAVITY FOR EVALUATION OF RF CRITICAL MAGNETIC FIELD OF THIN-FILM SUPERCONDUCTOR

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Abstract

For future accelerator, superconducting RF cavity has high gradient of 45 MV/m or more is demanded. To obtain such a higher gradient, there has been proposed a method of increasing an RF critical magnetic field of the cavity inner surface by coating of multi-layer thin-film superconductor. Their thickness is close to the London penetration depth. By producing a multilayer film structure in cavity inner surface, it is believed to improve the RF critical magnetic field, and to connect directly to high gradient. To demonstrate a creation of a thin film on a surface of Nb samples, an RF cavity with a thin film coated Nb sample is needed to measure the RF critical field of the sample. To adapt it to the cavity, to cool to cryogenic temperature and to establish the sample to supply the RF power, it is necessary to design a cavity to produce a strong RF magnetic field parallel to the surface of the thin film sample. We designed a mushroom shaped cavity made of Nb and input coupler. Resonant frequency is 5.2 GHz by calculation. We calculated the resonant frequency and the field distribution, compared with the measured values for the model cavity.

MULTI-LAYER THIN-FILM SUPECONDUCTOR

A superconducting thin film for a high electric field of an accelerator cavity application was proposed by Gurevitch 2006 [1]. The study of multilayer thin-film superconductor is being on a way in many institutes [2]. In order to achieve high acceleration gradients for the superconducting cavity of the second stage ILC accelerator, we started the study to evaluate a critical magnetic field of superconducting thin-films such as Nb_3Sn and NbN and MgB_2 deposited on the Nb samples. We chose an atomic layer deposition (ALD) method of film formation, which has an advantage of uniform and nm controllability for thickness on a complex inner-surface structure of cavity. In order to develop application method of ALD on Nb surface, we need to measure lower critical field at a frequency of several kHz using a small coil, a superheating critical magnetic field of RF frequency using RF cavity respectively, as well as RRR for thin-film on a sample. There is theoretical study to evaluate a thickness of each layer for the best performance of multi-layer thin film superconductor. We have shown that there is an optimum thickness of formed thin layer to get maximum superheating critical magnetic field [3]. Those are the target structure in this study.

DESIGN AND MANUFACTURE OF THE ALUMINUM MUSHROOM-SHAPED CAVITY

Calculation of Electromagnetic Field in the Cavity

A mushroom-shaped cavity has a shape of half hemisphere with flat bottom plate. It has an advantage to make strong magnetic field closing well inside of the cavity and facing to the sample surface of the bottom plate, on the other hand, a magnetic field on the hemisphere surface can be reduced compare to the bottom surface.

The previously designed mushroom-shaped cavity has high field sensitivity with dimension change of protrusion inward. In addition, it has also high sensitivity to the axisymmetric disturbance of the electromagnetic field by the insertion of the antenna, and the internal electromagnetic field is easily disturbed by the antenna. Furthermore, the resonance frequency of the target mode was close to the resonance frequency of the adjacent modes, so the mode separation was not enough. Since it was found that mode separation tends to improve by increasing the order of the mode, we newly changed the resonance frequency from 3.9 GHz to 5.2 GHz of the next higher order. Furthermore, by adopting an antenna shape which does not disturb the axisymmetry, more stable electromagnetic field design can be performed.

Resonant frequency corresponds to a fourth-order harmonics of 1.3 GHz which is the resonant frequency of the superconducting accelerating cavity of ILC. The shape of the cavity was based on the mushroom-shaped cavity of the SLAC study [4]. The stored RF power is limited by thermal superconductivity destruction of Nb of the cavity. We have designed a cavity so that the magnetic field of the sample surface to the magnetic field of the inner hemisphere wall holds a value twice or more. The electric field in the cavity inner wall has been designed to have minimum, in order not to generate field emission. A cylinder shape port at the top of the mushroom-shaped cavity is a coupled RF amplifier to put RF power into the cavity. The port is also used for a vacuum pumping port installation. CST MW STUDIO was used to design the cavity. By starting from the shape of SLAC cavity, model dimensions were optimized to have 5.2 GHz with similar elec-

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tric field and magnetic field inside. Then a shape of a bottom plate was modified to have strong magnetic field on the sample surface with weak magnetic field on the hemisphere surface. The bottom plate was extruded into the cavity, finally. Figure 1 shows final cavity shape and calculated electromagnetic field of inner surface in the cavity.

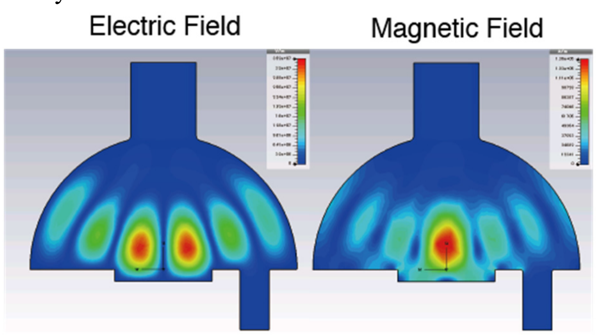

Figure 1: Electric and Magnetic field in mushroom-shaped cavity.

From the calculation, the resonant frequency of the target mode is 5.252 GHz. Frequency difference of Adjacent mode are +37 MHz and -92 MHz. They are enough wide mode separation. Maximum excited magnetic field on the bottom sample surface is 50810 A/m, on the other hand, along the inner surface of hemisphere, the maximum excited magnetic field is 30420 A/m. As a result, the ratio of the sample magnetic field to the hemisphere is 1.67. It means that we can test the critical field of the sample 1.67 times more than Nb.

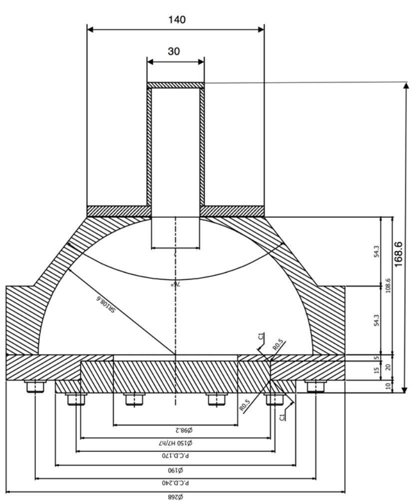

Figure 2: Cross-sectional drawing of mushroom-shaped Aluminum test cavity.

Manufacturing and Evaluation of Test Cavity

According to the electromagnetic design, a test cavity was designed mechanically and fabricated by an aluminium to check whether electromagnetic field in the cavity has a calculated field. Figures 2 and 3 are the drawing and the picture of the test cavity. They are divided to 6 parts, connected by bolts. The input antenna port and pickup antenna port were taped because of easy to change the dimension. They also have holes for bead-pull through holes.

Figure 3: Picture of mushroom-shaped Aluminum cavity.

The resonant frequency of the target mode is measured to 5.261 GHz. This is 9 MHz higher than the calculation. The mode separation was consistent with the calculation. In order to confirm the electromagnetic field of the target mode, we measured mode field distribution using bead-pull measurement on the path 1 shown in Figure 4.

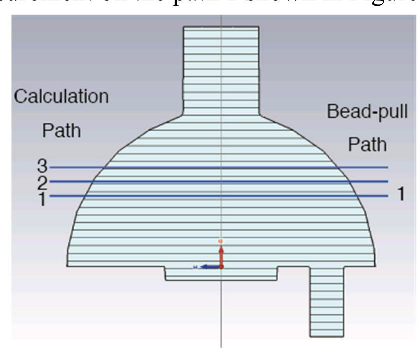

Figure 4: Paths of Bead-pull measurement (right side) and frequency shift calculations (left side).

The frequency shift on the path 1 of the bead-pull in Figure 4 is calculated. The orange points in Figure 5 are frequency shift by the bead-pull measurement at the 5.261 GHz and blue points are calculated one.

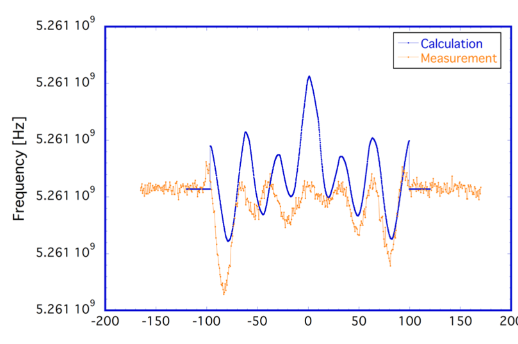

Figure 5: Comparison of bead-pull frequency shift between bead-pull measurement (orange) and CST calculation (blue), at 5.261GHz mode.

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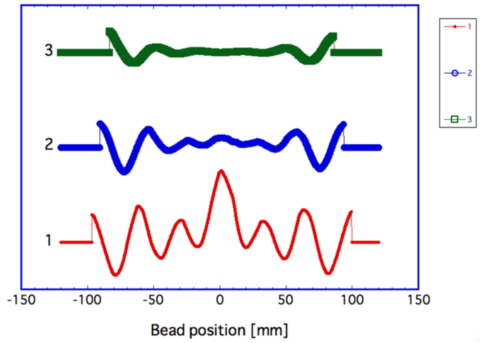

Figure 6: Comparison of calculated frequency shift on the three paths at 5.261GHz mode.
(Path 1 is bead-pull position, path 2 is 10 mm above the path 1, path 3 is 10 mm above the path 2)

Since strong magnetic field at the center of the cavity in the target mode, it should be strong positive frequency shift in the center of the cavity. However, we observed relatively weak positive frequency shift. It seems that the magnetic field on the bead-pull path is weaker than the calculation. So we try to compare the frequency shift calculation on the path 2 and 3. They are 10 mm and 20 mm above the path 1. Calculated frequency shift of them are shown in Figure 6. We thought that our bead-pull measurement seems to consistent with the calculation between path 1 and path 2. The target mode electromagnetic field can be confirmed. These mismatches seem to come from the difference of the experiment antenna shape and insertion length with calculated model. There is a need to improve the model for antennas shape and insertion length.

DESIGN OF NB-MADE MUSHROOM-SHAPED CAVITY

Figure 7 shows design proposal of the Nb-made mushroom-shaped cavity. The entire cavity needs to transition to the superconducting state, to create a body Nb, a flange with NbTi. The basic thickness of the cavity is thinking 2.8mm. The method of fixing the bottom sample plate will be done by indium seal. Also, the bottom plate and hemisphere flange are connected using indium seal. Input antenna port, pick up antenna port and vacuum port are connected by using hexagonal metal seal. Input antenna is used to excite the cavity from the hemisphere top. Pickup antenna is a plan to be attached to the bottom plate.

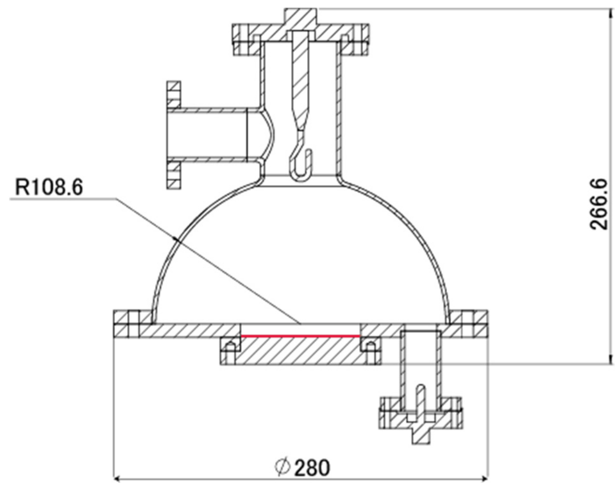

Figure 7: Cross-sectional drawing of mushroom-shaped Nb cavity. (Red line shows sample surface.)

SUMMARY

The design modification of the cavity to measure the RF critical magnetic field of the multi-layer thin-film superconductors was carried out. Aluminum test cavity was designed and manufactured. The electromagnetic field distributions of the test cavity were evaluated by bead-pull, and they seem to consistent with the calculation considering the field distortion by the input antenna shape and insertion length. Design of Nb model cavity was performed.

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