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FABICATION OF Nb MUSHROOM SHAPED CAVITY FOR EVALUATION OF MULTI-LAYER THIN FILM SUPERCONDUCTOR

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Abstract

The accelerating gradient of the Nb superconducting RF cavity seems to reach the limit due to the RF critical magnetic field of the Nb material. To obtain 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. It is needed to demonstrate improvement critical magnetic field of the RF cavity coated with multi-layer thin-film superconductor. To optimize thin-film superconductor, sample tests are required. A cavity for sample test is necessary to produce a strong RF magnetic field parallel to the surface of the sample for evaluating RF critical magnetic field. For such a cavity, we designed a mushroom shaped cavity made of Nb which is operated in cryogenic temperature. Input and pick up antenna coupler are also designed electrically and mechanically. The connection design of sample plate and cavity bottom plate in superconducting state is also designed. The Nb mushroom shaped cavity is under fabrication. Fabrication method and status are reported in this paper.

INTRODUCTION

A technique of improving the Q value and acceleration electric field of the cavity by adding a small amount of nitrogen at the time of annealing and by using a method of improving the critical magnetic field leading to a high acceleration electric field by stacking superconducting layers are developing for high performance of the superconducting cavity made of Niobium (Nb) [1, 2]. Those methods improve greatly RF loss and acceleration electric field. In order to optimize each parameter and thin film of the surface treatment, it is necessary to evaluate them repeatedly for manufacturing a cavity having such high performance. However, many cavity evaluations are large-scaled, so that a device for evaluating a test piece subjected to the same treatment is required. Particularly, in the technique using a multilayer thin film structure, it is difficult to form a uniform film from the complicated shape of the cavity and its size. Further, in order to optimize the film forming process, it is necessary to perform film formation many times. Therefore, evaluation with a test piece is desired so that it is smaller than the cavity and easy to form a film, and it is easy to form many times. In this report, in order to evaluate the performance of test piece of multilayer thin film superconductors for superconducting cavity, we report on the design and fabrication of cavities for measuring critical magnetic field at cryogenic temperature.

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DESIGN, FABRICATION AND EVALUATION OF TEST AL CAVITY

Design and Fabrication of Al Mushroom Shaped Cavity

In evaluating the multi-layer thin-film superconductor for the superconducting cavity, we considered that the following physical quantity evaluation is necessary.

- Superconducting transition temperature (Tc).
- RF surface resistance (Rs).
- critical magnetic field (Hc).

As a device for evaluating these physical quantities, we considered to use a cavity resonator that can replace the test piece repeatedly. This is because excitation of a strong electromagnetic field is possible, the above physical quantity can be measured all at once and it is thought that evaluation of many test pieces becomes easy.

First we started the design with SLAC's 11.4 GHz cavity [3]. The resonance frequency was chosen to 5.2 GHz

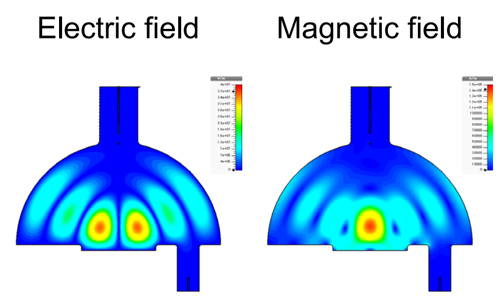

Figure 1: Calculated electromagnetic field in the mushroom-shaped cavity.

and the resonance mode was also chosen to TE_{013}.

Figure 1 shows the electromagnetic field excited in the designed cavity calculated by CST MW STUDIO [4]. As an initial step toward the fabrication of a Nb superconducting cavity, an Al-based cavity was proposed to evaluate the target resonant frequency, the separations of neighboring modes, and the electromagnetic field distribution of the target mode. Figure 2 shows the cross sectional drawing of the aluminum test cavity.

Evaluation of Al Mushroom Shaped Cavity

Figure 3 shows the frequency displacement during bead-pull measurement when a small metal cylinder is inserted into the test cavity and swept. Frequency shift calculated by CST MW STUDIO using perfect conductor cylinder is also inserted. Although there is a difference in frequency deviation along the sweep direction due to the cavity loss and the coupling of the antennas. Since the

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frequency deviation shapes are similar, it can be evaluated that the excited electromagnetic field distribution is similar the calculated electromagnetic field distribution. Based on these results, we fixed the design of the inner space and the mechanical design of the Nb based cavity was started.

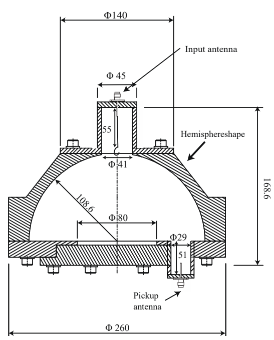

Figure 2: Cross-sectional drawing and picture of the Al test mushroom-shaped cavity.

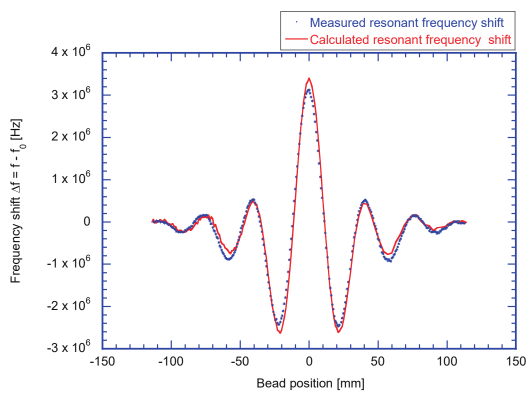

Figure 3: Comparison of bead-pull frequency shift between bead-pull measurement (orange) and CST calculation (blue), at 5.261GHz mode.

DESIGN OF NB BASED MUSHROOM SHAPED CAVITY

Mechanical Design of Cavity

Figure 4 is a design drawing of the mushroom shaped cavity made of Nb. In order to achieve a high Q value, the entire cavity needs to transition to a superconducting state. Therefore, the cavity is made of Nb and the connection flange is made of NbTi. Since the hemispherical part of the cavity is manufactured by press method, it was designed to be 2.8 mm thick like the TESLA type superconducting cavity. The sample part of the bottom plate is planned to be vacuum sealed with Nb gasket or indium seal. Aluminum metal seal is used for the antenna port flange and the vacuum evacuation port flange like the TESLA type superconducting cavity. The input antenna for cavity excitation was shaped like a hook and designed to couple with the internal magnetic field. We designed a pickup antenna inside bottom pickup port so that axial symmetry of the internal electromagnetic field is not disturbed as much as possible and 2 port measurement is possible.

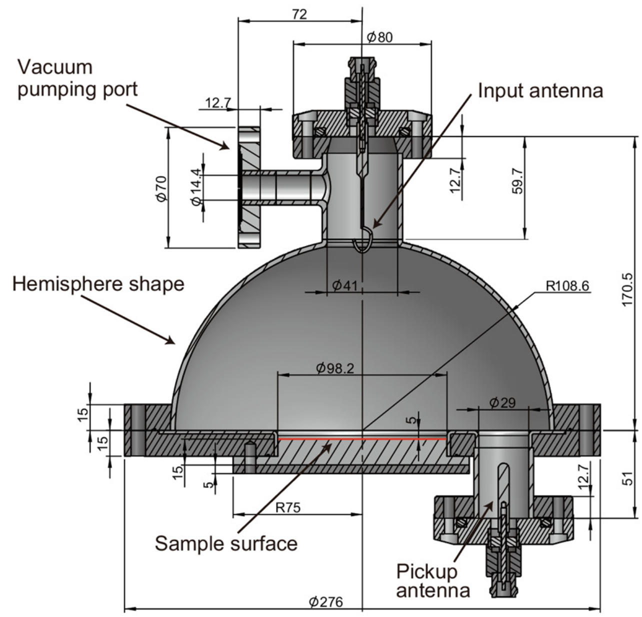

Figure 4: Cross sectional drawing of Nb-based mushroom-shaped cavity.

Vacuum Leak Test of Nb Gasket

The flange is used for exchanging the test piece. If the RF loss at the flange and the seal material is large, it causes a quench of the whole cavity. Therefore, Nb gasket or indium seal is to be used for the seal material of the flange connecting the test piece and the cavity. In order to evaluate Nb gasket, we fabricated a Nb gasket for ICF 70 flange and a vacuum flange with surface without touching edge, and conducted a vacuum sealing test.

Figure 5 shows the outline of the test. The test was conducted in the following two ways.

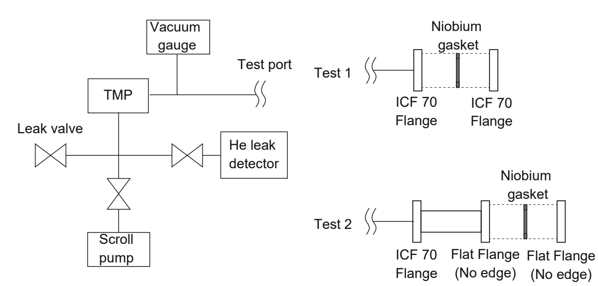

Figure 5: Leak test setup of Nb gasket and flat flange.

- Test 1: Leak test using helium leak detector after immersion in liquid nitrogen Nb gasket for ICF 70 flange with overall baking.
- Test 2: Leak test using helium leak detector after liquid nitrogen immersion face touch flange and Nb gasket with overall baking.

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In Test 1, there was no leak in the test at room temperature, but a leak occurred after immersion in liquid nitrogen. In Test 2, a leak at room temperature was occurred. For this reason, we plan to retest by using a vacuum annealed Nb gasket using the same flanges.

Press Fabrication Test of Half-Size Hemisphere Cell

Before manufacturing the actual cavity, the hemispherical part, which is not easy to shape in the press forming, was manufactured in half size. An oxygen free copper plate with a thickness of 3 mm was used as the material to be pressed, and an aluminum alloy was used for the press die. The shape of the pressed hemispherical part was compared between the design and the pressed one using a three-dimensional measurement system. Figure 6 shows the hemispherical part pressed and the result of shape measurement. The dashed line in red is the design value, and the solid line in black is the shape after press.

Evaluated region was set to the lower z region less than circle (X – X'), because the neck region is difficult to form in the miniature hemisphere cell. The maximum error of the hemisphere shapes along the dashed lines in Fig. 6 of a – a', b – b', c – c', and d – d' was measured to be 1 mm, as obtained from a comparison between the measurements (solid, black) and the designs (dashed, red) in Fig. 6. In addition, we measured the circle profiles at an equator (A – A') in Fig. 6. The maximum error was 30 μm. The required accuracy in the case of half-size hemisphere is within 1 mm, to keep the magnetic field ratio between sample surface and hemispherical surface larger than 2.

PLAN OF PERFORMANCE TEST OF NB MUSHROOM SHAPED CAVITY AT CRYOGENIC TEMPERATURE

Cavity Installation Method to Vertical Test Stand

In the KEK Superconducting RF Test Facility (STF), vertical cryostat was placed for superconducting cavity evaluation at 2 K cooled with liquid helium. In this existing measurement system, Nb made mushroom cavity for evaluation of multi-layer thin-film superconductor is placed and cryogenic test is planned. Figure 7 shows the outline. The measurement cavity is suspended from the cryostat top plate and immersed in liquid helium at the bottom of the cryostat. In addition, it is evacuated with an ion pump placed on the top plate, and a high vacuum of about 10 - 8 Pa is maintained during measurement.

Power Test

In order to evaluate the RF characteristics of the cavity cooled to 2 K, RF power of about 1 W is input using a network analyzer. The Q value of the cavity and the coupling of each antenna are evaluated and compared with the design value.

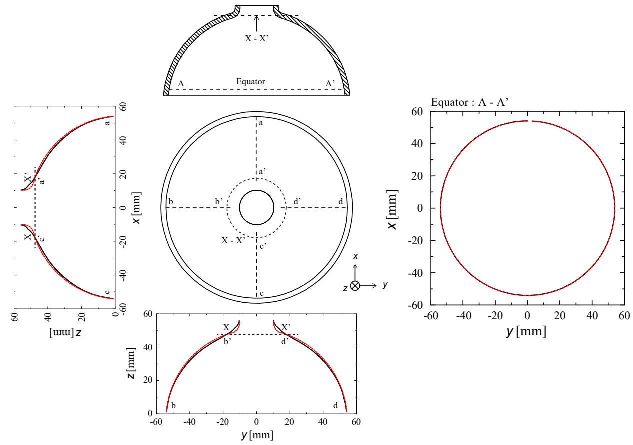

Figure 6: Comparison of press forming shape between design and 3D measurement. Red line is designed line, black line is 3D measurement.

Moreover, in order to realize superconducting quench or magnetic flux penetration of multi-layer thin-film superconductor, we plan to input electric power of about 50 W at maximum.

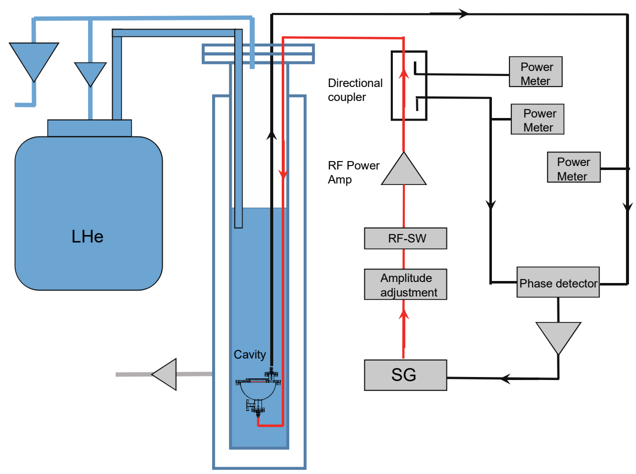

Figure 7: Vertical test setup of mushroom-shaped cavity.

CONCLUSION

We construct and evaluate test cavity for critical magnetic field evaluation of multi-layer thin-film superconductor. We fabricated Al test cavity and confirmed electromagnetic field distribution by bead-pull perturbation measurement with disturbed by antenna shape and insertion length.

We design Nb based cavity based on Al test cavity design. Press test of half size hemisphere cell was performed and confirmed error within design value.

We also test Nb gasket for sample flange sealing. Leak was occurred. Further study is necessary.

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[4] https://www.cst.com/Products/CSTMWS