PROMISING PERFORMANCE OF THE Nb/Cu CLAD SEAMLESS SUPERCONDUCTING RF CAVITIES

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ABSTRACT

For future large applications of superconducting RF cavities, one has to fabricate cost-effective cavities with high electric-field gradients. We have proposed the fabrication of L-band seamless cavities from Nb/Cu clad material in order to eliminate the electron beam welding process. A feasibility study on the fabrication of 1.3 GHz Nb/Cu Clad single cell cavities from the clad sheet material was done. Three single cell Nb/Cu clad seamless cavities were fabricated by the collaboration with INFN-LNL in Italy. In this paper, cold test results of seamless type cavities obtained by the spinning method are presented. The best performance of the cavities was Eacc = 25.1 MV/m with Qo=2.5X10^{10} at a temperature of 1.4 K, which is very promising.

1 _INTRODUCTION

At KEK, in order to reduce the amount of the expensive niobium material and to eliminate the complicated electron beam welding work, Nb/Cu clad seamless cavities which combine both economical efficiency and a high gradient have been developed [1]. These cavities will be fabricated by the hydro-forming method (hydrostatic bulging) with a clad seamless tube which is composed of a thin niobium wall inside a thick copper tube. In hydro-forming, cracks are not produced in the niobium surface because the deformations small. The thick clad tube of the three-layer structure (Cu/Nb/Cu) is fabricated by hot isotropic pressure (HIP) bonding and drawn out to a diameter and wall thickness in preparation of bulge forming. The research and development of these cavities, including the clad tubes, is carried out by the collaboration with Toshiba Corporation.

In parallel with the development of these clad tubes and cavities, in order to evaluate the feasibility and problems of the Nb/Cu clad material for cavities, three L-band single cell cavities have been fabricated by forming a Nb/Cu clad plate with the spinning process at INFN-LNL [2], which is in the collaboration with KEK. The plates were made using explosive bonding, the thickness was reduced to 4 mm by rolling. These cavities, which were named KENZO-1, KENZO-2 and KENZO-3, were tested at KEK. Previous cold test results for KENZO-1 and KENZO-3 were reported earlier [1, 3, 4]. _

In the following tests, a maximum electric field gradient of 25.1 MV/m with a maximum Q-value of 2.5X10^{10} was obtained in spite of the existence of cracks [4] on the niobium surface which were formed during the spinning process. This seems promising for the Nb/Cu clad material for cavities. However, some problems to be solved were found out in these tests. One problem is a change of the Q-value by a thermoelectromotive force from due to a different cooling method. The other problem is the Q-drop after a thermal quench. We present these problem in this paper. In addition, the surface resistance of the Nb/Cu clad cavities vs. external magnetic field was measured from 0 to 210 mG. In this paper, the experimental results are also reported.

2 HIGH GRADIENT PERFORMANCE WITH Nb/Cu CLAD CAVITIES

At the first we report the promising results on the Nb/Cu clad cavities. In this cavity fabrication, we used the niobium material with RRR=100. It has to be emphasized that even in such a low RRR value, the high gradient of 25 MV/m was achieved, which is already the TESLA target field. As presented in Fig. 1, in the niobium bulk cavities with RRR=100, the maximum electric gradient has been limited to 20 MV/m. The number of 25 MV/m is higher compared to the niobium balk cavities with the same RRR value. This effect should be brought by the higher thermal conductivity in the Nb/Cu clad material.

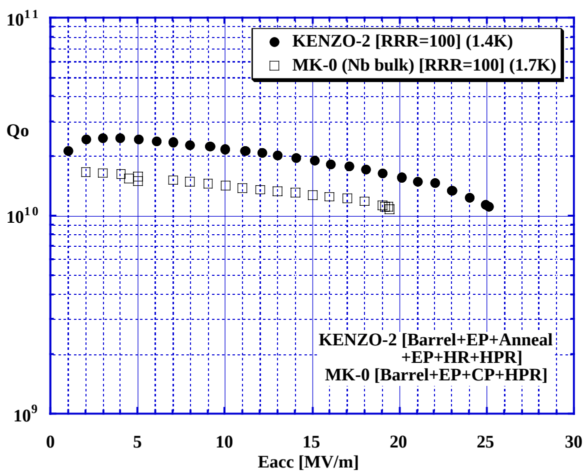

Figure 1: High gradient performance in the Nb/Cu clad cavity.

3 LOW Q PROBLEM IN FAST COOLING DOWN

By measuring the change of the Q-value and the residual resistance vs. the cooling method of the cavities, it was confirmed that the persistent current from the thermo electromotive force affects the performance of the cavities.

In addition we measured a thermoelectric voltage between niobium and copper for a thermo-coupler by a niobium wire and a copper wire. The measurement result is seen in Fig. 2. The voltage of 0.93 µV/K was observed around 10K.

The thermoelectric current problem is well known in the cavities fabricated with composite materials [5]. The mechanism is understood as following. When the current is generated by the thermoelectromotive force, during cooling down it is trapped in the superconductivy state in niobium at the critical temperature of Tc = 9.25 K. This current interacts with microwaves when it is fed into the cavity, and results in an additional surface resistance.

We have measured the variation of the Q-value in the following two conditions: (1) the current seems trapped by fast cooling, and (2) the trapped current was extinguished by warming up to 10 K. In Fig. 3, at first we by a fast cooling. Then the cavity was warmed up to 10K and exposed this temperature for 10 minutes. After this, the cavity was

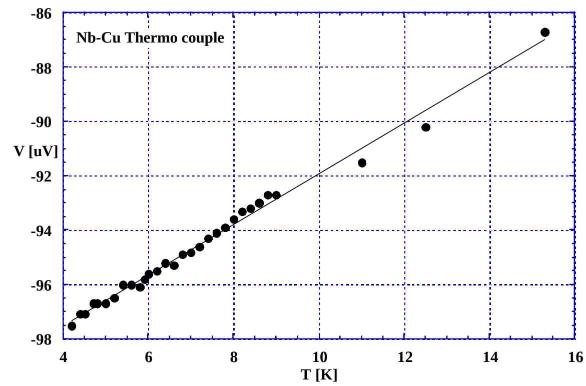

Figure 2: Thermoelectric voltage of Nb-Cu thermocouple.

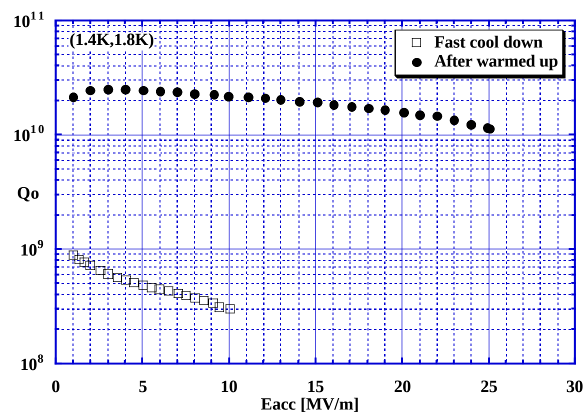

Figure 3: Improvement in Q-value by warming up to 10 K.

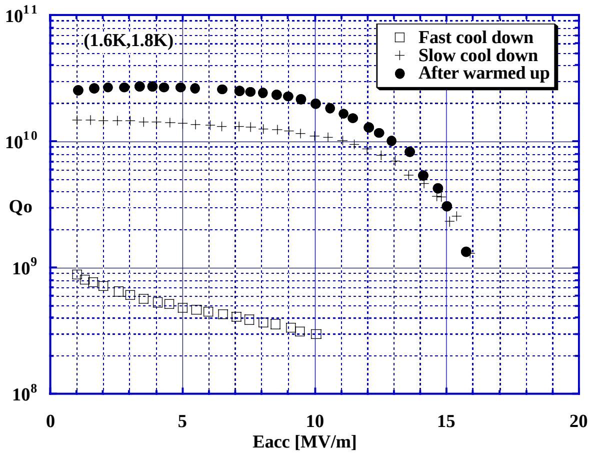

Figure 4: Improvement of Q-value by a slow cooling down.

cooled down again pretty fast to 4.2 K. Then, it was cooled down to 1.9 K and measured the Qo-Eacc curve (●). A remarkable improvement in Q-value was observed after the warming up.

We have measured the Q-value of a cavity when it was slowly cooled in order to suppress the trapped current by the thermoelectromotive force. The comparison of Q-values with fast-cooling (❑), slow-cooling (+) and warming up (●) is shown in Fig. 4. The slow cool down: condition can improve the Q-value partially but it is not perfect. This result means that a slow cool down can not eliminate perfectly the problem of thermoelectric force during cooling down. The warming up method seems to be a better cooling method. When the performance is limited by the current, the performance must be improved by the elimination of the trapped current when the cavities enter the normal state.

4 Q-DROP AFTER QUENCHES

At a quench, the same phenomena of the thermo_electromotive_force occurs due to a temperature rise, and a decrease in the Q-value is observed. In Fig. 5, the first quench occurred at 16 MV/m (❍). After quenches, the Q-value dropped successively (■) and finally degraded about one order of magnitude (❑). This Q-drop was recovered to the original value by warming up to 10 K (+). The effect is much small ,however, this kind of problem is also observed in the niobium bulk cavities [6].

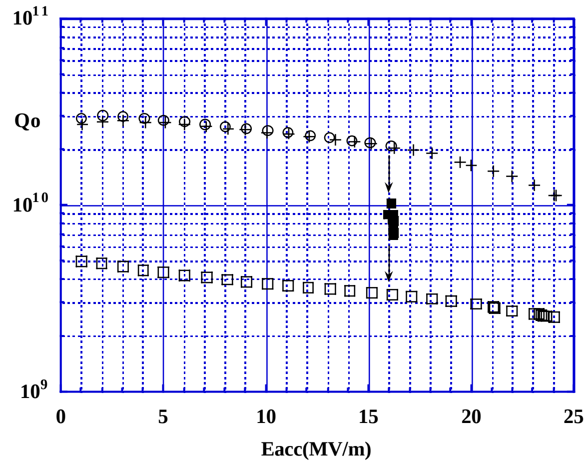

Figure 5: Successive Q-dropping by quenches, and Recovered to the original value by warming up.

5 EXTERNAL MAGNETIC FIELD EFFECT

Superconducting cavities are easily affected by an external magnetic field, and the performance degrades with the increase of surface resistance due to the trapped magnetic flux in the superconducting intermediate state. This fact becomes a problem when the cavities are placed close to various magnetic devices in the beam transport system. For this reason, the cryostat of the conventional vertical test system for the superconducting RF cavities has a magnetic shield. Dr. Ono et al. reported the effect of the external magnetic field in a bulk niobium cavity [7].

In the clad cavity, it is expected that lattice defects from thermal stress due to the difference between niobium and copper thermal expansion coefficients in the niobium surface function as the pinning centers, which does not happen in bulk niobium cavities. In order to confirm this, the performance of the Nb/Cu clad cavity was measured by applying a magnetic field with a solenoid coil parallel to the axis of the cavity. The magnetic field was only changed when the cavity was not in a superconducting state. The relationship between the residual resistance, which is obtained by a curve-fitting the temperature-dependence of the surface resistance of the cavity, and magnetic field is shown in Fig. 6. The residual resistance of the niobium bulk cavity is also shown for a comparison. Conversely to our expectation, in the clad cavity the larger increase of the residual resistance was observed by the applied external magnetic field. The dependence of the strength of magnetic filed was :

0.56 n /mG for Nb/Cu clad cavity (1).

1400°C annealed it was:
0.43 nW/mG for a well annealed Nb bulk cavity (2).
The value of Nb/Cu clad cavity is about 30% larger than that of the bulk niobium cavity.

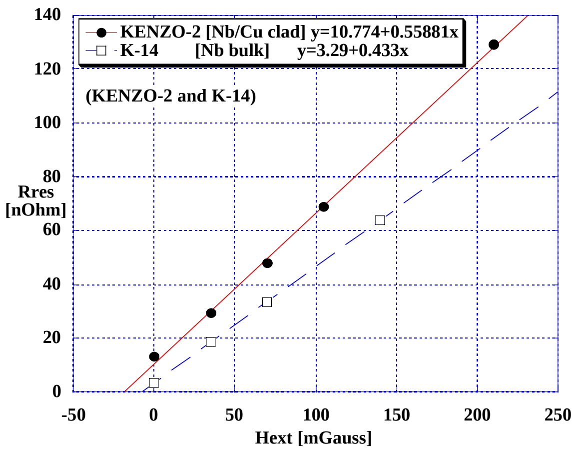

Figure 6: Residual resistance as a function on external magnetic field.

6 SUMMARY

In the cavity with a clad material, we achieved a high gradient of 25 MV/m. This number is higher to compare the niobium bulk cavity with same RRR value. As we expected, clad cavities are very promising for the high gradient performance. On the other hand some problems were observed: degradation in the Q-values due to the_electromotive force. The problem related to cooling is avoided by warming up to the normal state in order to extinguish the trapped current. However, for the other Q-drop after quenches, a new idea has to be developed in order to resolve the problem.

The results from the KENZO-2 cavity with comparatively small cracks showed good performance; 25 MV/m. However, the high gradient performance might be still effected by these cracks. It is expected that remarkable improvement may be obtained by using the hydro-bulge forming process.

As for the effect of external magnetic field, it is about 30% higher than that of a bulk niobium cavity, and it is speculated that the magnetic field will easily penetrate into the niobium due to the cracks. _

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