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Superconducting Resonators for Heavy Ion Acceleration at JAERI

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Abstract

Number of superconducting coaxial-line quarter wave resonators have been built for the JAERI Tandem-Booster. Resonator performances have been measured with 12 resonators. They had an accelerating field level of around 6.5 MV/m with an rf input of 4 watts. One of them had a maximum accelerating field level of 12.6 MV/m or a peak surface electric field of 58 MV/m. Problems in the surface treatments and Q degradation in thermal cycles are also reported.

1. Introduction

A superconducting heavy ion booster consisting of 44 superconducting quarter wave resonators of $\beta_o = 0.1$ and $f_o = 129.8$ MHz [1-4] is being built for a tandem accelerator at JAERI. A view of a resonator is shown in Fig. 1. This paper describes the status of the resonators, while cryostats, refrigerators and others are reported elsewhere in this workshop[5].

Four of the 130 MHz resonators were built for the buncher and de-buncher in early part of the development[2,4] after the initial studies on quarter wave line structures[6-8]. Their accelerating field levels were 5-6 MV/m at an rf input of 4 watts and reached to 7 MV/m. Such the high field levels were obtained by applying helium processing. The fact that the helium processing was necessary to suppress electron field emission and to raise the field levels means that the niobium

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surfaces were not clean enough. We, therefore, did an experiment of vacuum drying at the end of surface treatments. The result is presented in section 2.

Sixteen of the fourty resonators for the linac have been built. A brief description on their fabrication is in section 3. They are receiving final surface treatments and performance tests and being assembled in their cryostats. Their results of performance tests are described in section 4. Problems which happened in the surface treatments are presented in section 5.

Q degradation in thermal cycles has been a recent topic in RF superconductivity. The result of a recent experiment of thermal cycles with a quarter wave resonator is presented in section 6.

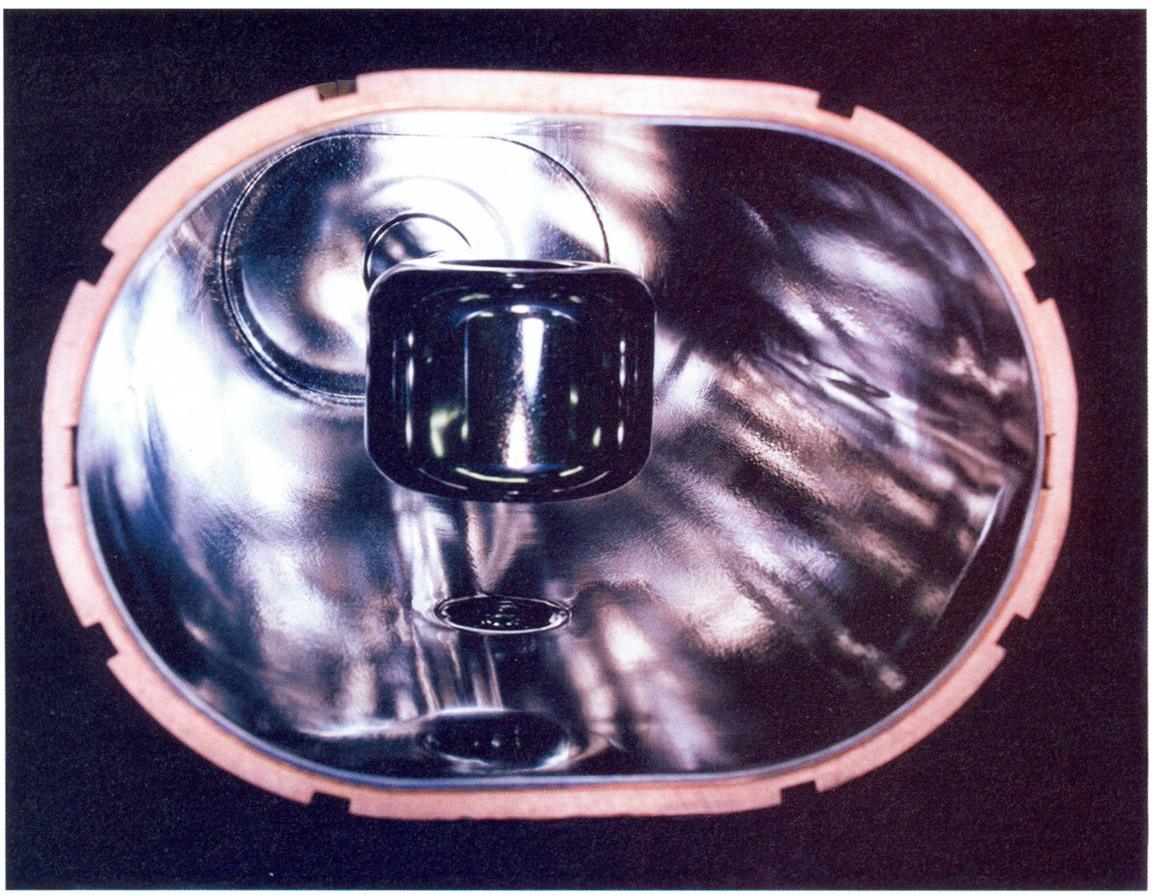


Fig. 1. An inside view of superconducting quarter wave resonator.

2. Reduction of electron field emission with improving drying methods

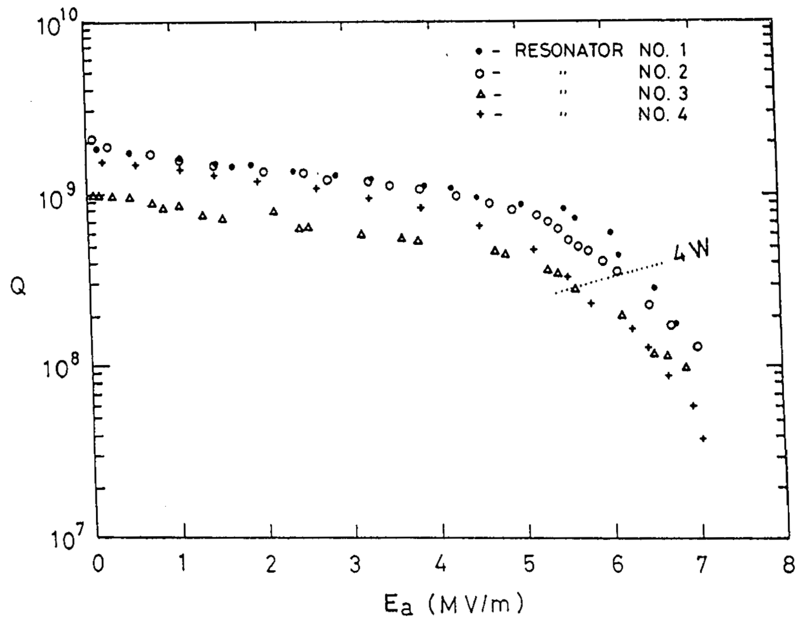
After resonators are delivered to our lab, we treat the niobium surfaces with electropolishing by 10 - 30 μm and rinses with 15% HF, 10% H_2O_2[9,10] and de-ionized water. Our way of drying wet niobium surfaces after rinsing with 18 mega-ohm*cm de-ionized water started with nitrogen blows. Q-E_a curves, where E_a is the accelerating field gradient, shown in Fig. 2.a) are the result obtained with the resonators which were dried with nitrogen blows. The curves were obtained after the helium processing with a 1.2 kW rf amplifier at 2×10^{-5} Torr. They still have Q degradation above 5 MV/m due to electron field emission.

Motivated by use of vacuum drying at KEK[11] and other labs, two of the resonators were experimantally treated again with electropolishing followed by rinsing and vacuum drying. During rinsing and drying, the resonators were warmed. The result is shown in Fig. 2.b). Helium processing made no difference to the Q-E_a curves. This result indicates that dust which had caused electron field emission was reduced effectively by employing vacuum drying. We naturally had an increase of the maximum field levels from 7 to 8-9 MV/m.

We continued to use vacuum drying for the resonators made for the booster linac. However, we had troubles many times. The trouble was related with use of a dummy end plate with a rubber gasket which could not be clean enough. Bubbling of water on the rubber or leaks through the rubber made the niobium surfaces dirty. We have, then, turned to natural drying with a warm up to 35 - 40 °C after an additional rinse with methanol. There seems to be no significant difference in Q-E_a curves compared with the data obtained after vacuum drying.

3. Fabrication of resonators for the booster linac

Sixteen resonators have been built for the linac. There has been no change in the resonator structure from the four resonators made earlier. The industry made many improvements to fabricate a number of resonators. The improvements or changes which might affect the resonator performance are as follows: The vaules of residual resistance ratio(RRR) of the niobium used were about 90 for 8 resonators of No.1 to No. 8 and 150 ± 30 for the rest 8 resonators, while they were about 80 for the earlier four resonators. Bonding conditions of niobium-copper composite plates were changed so that the wave size of the boundary a)



b)

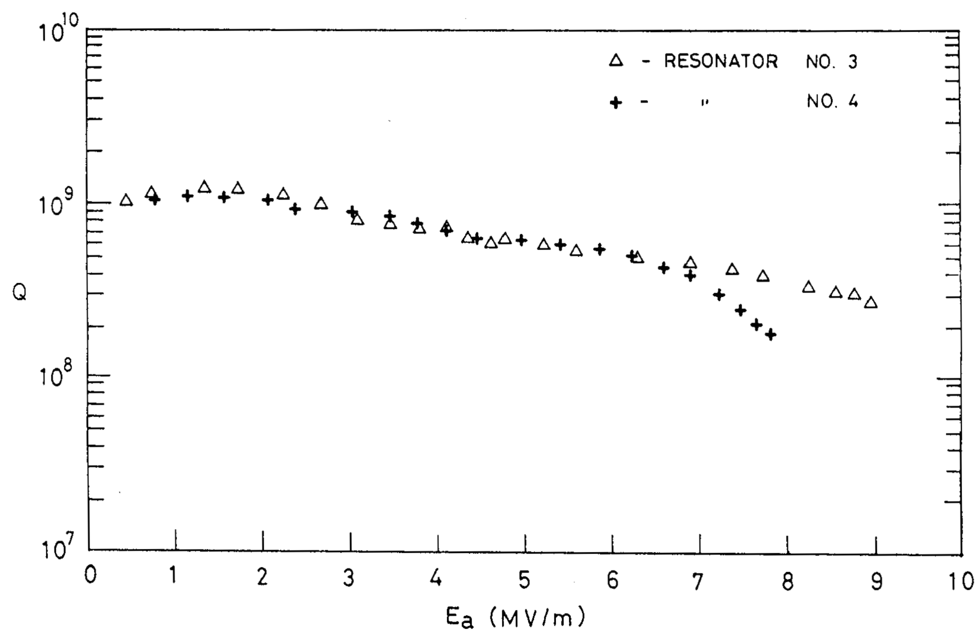


Fig. 2. Resonator performances of 130 MHz super conducting quarter wave resonators measured at 4.2 K.

a); The resonators were dried with nitrogen flow at the end of their surface treatments.

b); Two of them were dried with vacuum drying method at the end of 2nd surface treatments.

between niobium and copper was decreased to an order of 0.1 mm in peak-to-peak amplitude to make the fabricating processes up to electron beam welding easier and reliable. Baths for electropolishing were renewed to bigger ones. Some resonators had less shiny surfaces in part on their center conductors. We have not yet known what caused the problem. Those center conductors were repolished till they looked satisfactory. The heat treatment temperature was lowered to 950 °C from 1000 °C; the heat treatments were done with center conductors after welding all their parts and after electropolishing by an order of 75 um. With this temperature change, the niobium surfaces were covered with fewer precipitated particles looking white during the second heat treatment.

After the resonators were delivered to our lab, they had surface treatments of small amount of electropolishing, rinses with water and 15% HF, ultrasonic cleaning with 10% H_2O_2 and de-ionized water, a rinse with 18 mega-ohm*cm de-ionized water and drying in a clean room.

4. Off-line performances of the linac resonators

Twelve resonators have had final surface treatments and performance tests. As a summary of their performance tests, the maximum levels and the accelerating field levels at an rf input of 4 watts are shown in Fig. 3. In these figures, similar data of the four resonators for bunchers are also shown for a comparision. As a result, accelerating field levels of higher than our design value of 5 MV/m at the rf input of 4 watts have been obtained. There were many around 6.7 MV/m which gives an acceleration of 1 MV; the acceleration length of the resonators is 0.15 m. Maximum field levels were normally higher than 7 MV/m; they would be attributed to the improvement of drying method. One of them, of which Q-E_a curve is shown in Fig. 4, reached 12.6 MV/m. This value means the peak surface electric field of about 58 MV/m or the peak magnetic field of about 950 G. These values are as high as those obtained by J. Delayen et al. with coaxial quarter-wave and half-wave resonators[11,12].

On the other hand, the values of Q obtained with the resonators for the linac tended to be low. The low field Q values are shown in Fig.5. The low field values were lower than those values of about 2 x 10^9 obtained with buncher resonators which are also presented in Fig.5. The troubles during the resonator treatments are described in the next section.

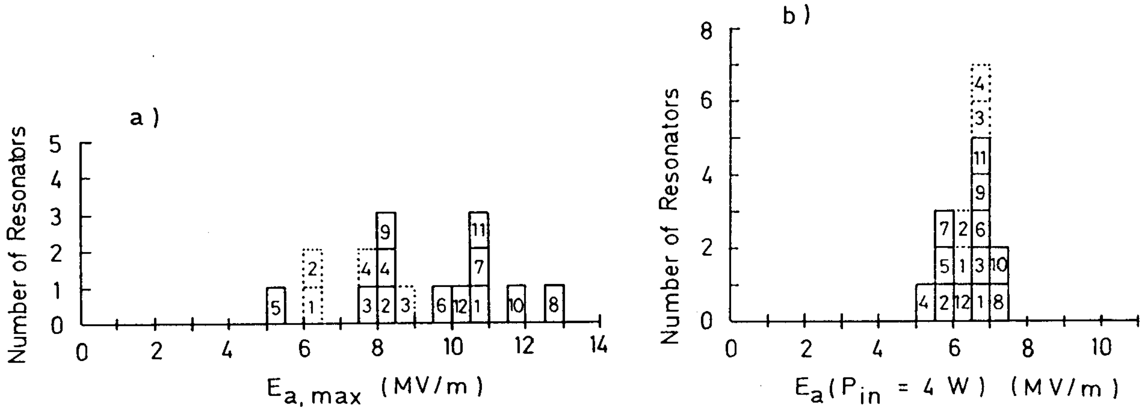


Fig. 3. Resonator performances at 4.2K.
a) Maximum accelerating field levels. b) Accelerating field levels with an rf input of 4 watts. Numbers in the counts are resonator identification numbers. Resonators enclosed with dotted lines are those for the buncher and de-buncher of the booster. The others are those for the booster linac.

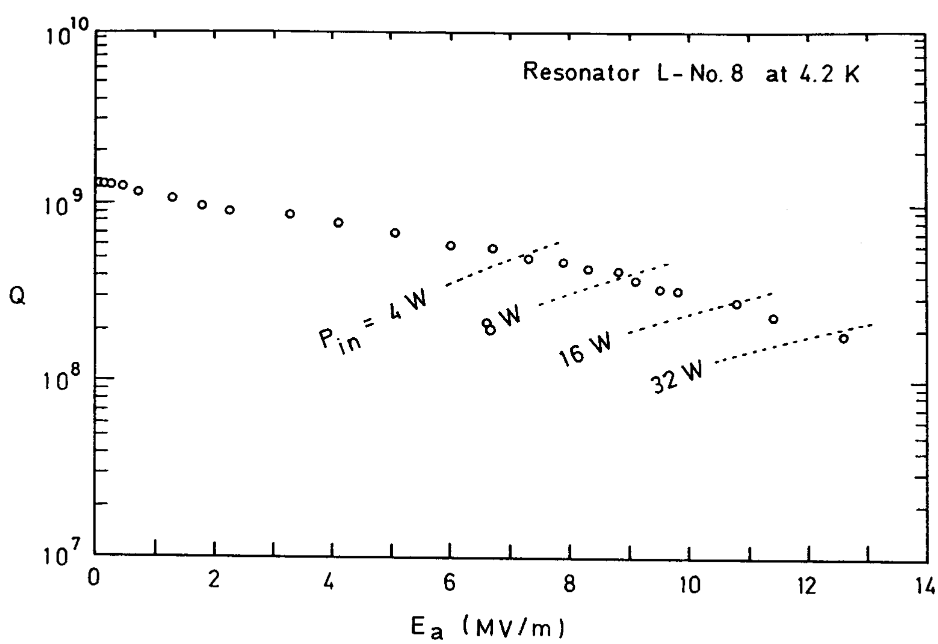


Fig. 4. Performance of a superconducting quarter wave resonator.

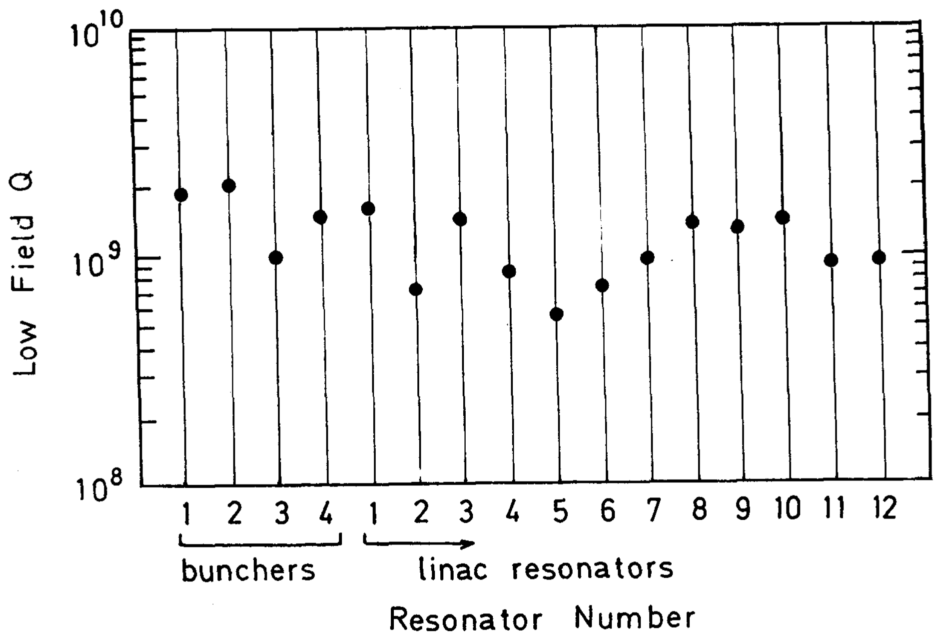


Fig. 5. Low field Q values obtained with 4 buncher/de-buncher resonators and 12 linac resonators.

5. Problems in electropolishing

Before we got the result of Fig. 3 or 5, several resonators were treated again because of low Q. A resonator, which is labeled with No. 4, had Q of an order of 1 X 10^{8}. Main rf loss was found on its outer conductor. The outer conductor interior surface was covered with small gray spots, which refrected the crystalline structure of the niobium. It was hard to remove the spots by electropolishing. The Q was improved only with a treatment starting from mechanical polishing. Another resonator, No. 2, had also gray spots on the outer conductor surface. It resulted in the value in Fig. 5. Those chemically inactive gray spots would have appeared in electropolishing. A poor flow of polishing solution was a possible factor to let them appear. The flow rate of the circulation was, then, considerably increased to an order of 20 1/m from the resonator No. 7, while the total volume of the solution was 18 1. Since then, we have not met embarrassing Q values. Something, however, still remained to cause the Q values lower.

6. Experiment of thermal cycles

Recently Q degradation during cooling time has been observed in different laboratories. A systematic experiment was undertaken at Saclay[14]. The experiment showed clear Q degradation after a warm up to intermediate temperatures with a 1.5 GHz cavity. At DESY, Q degradation occured successively after second cool down with 500MHz cavities[15].

It is interesting to know if our 130 MHz quarter wave resonators made of niobium and copper present such Q degradation. We recently made an experiment with one of the quarter wave resonators, No. 12. The thermal cycles with the resonator is shown in Fig. 6. The measured Q values are shown in Fig. 7. The first cool down took 6 hours, in which it took about 1.5 hours to pass the temperature range of 200-100 K; It was a fast cool down. The second measurement was done after a warm up to 140-160 K for 11 hours. Clear Q degradation was observed. The rf loss was dominant on the outer conductor, while it was evenly distributed to the outer and center conductors in the first cool down. The third cool down after a warm up to the room temperature brought about a complete recovery. We added the fourth cool down, which included a 13 hours long stop at 140 - 160 K. There was no Q degradation in the slow cool down. The values of Q, rather, increased with repeating cool-downs from the room temperature.

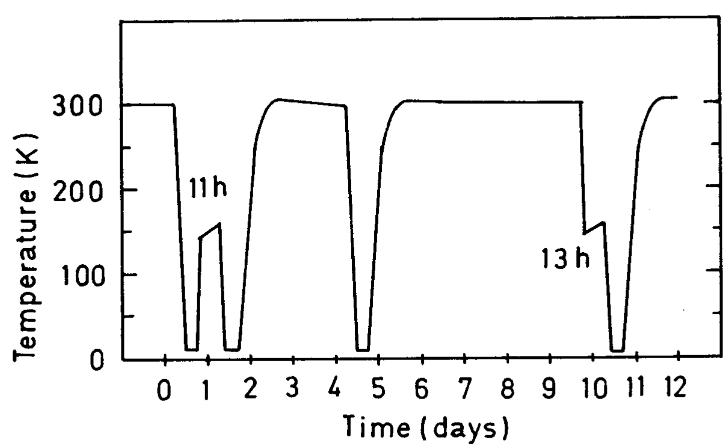


Fig. 6. Thermal cycles with a 130 MHz quarter wave resonator.

In reviewing records of other resonators, slow cooling rates tended to provide higher Q values than fast cooling rates. Resonator No. 7 to No. 10 were cooled in 24 hours with a stop around 50 K over a night, in which it took about 3 hours to pass the temperatures from 200 to 100 K, while No. 11 and No 12 were cooled in 6 hours. Their low field Q values can be compared in Fig. 5.

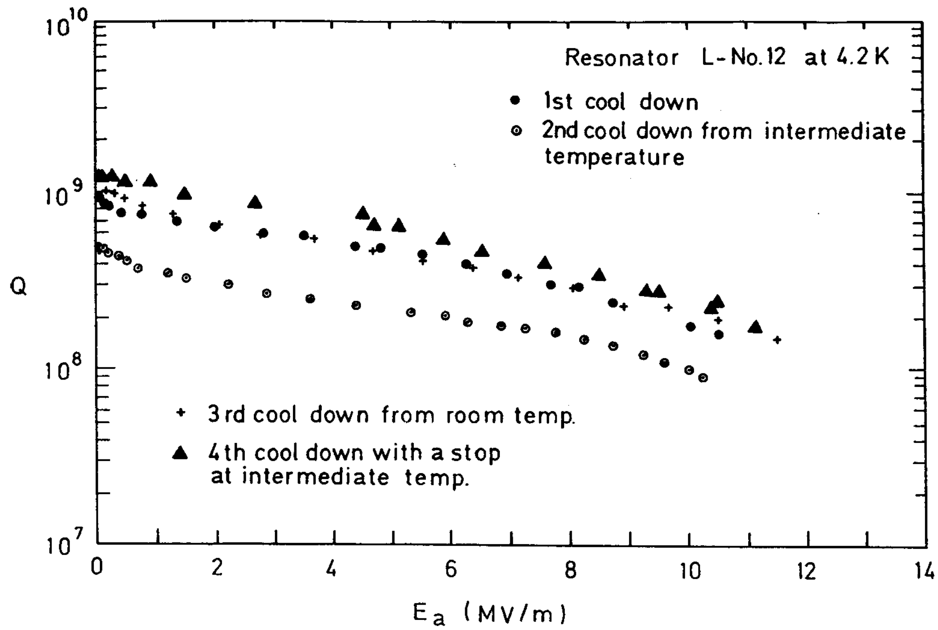


Fig. 7. Resonator performances of a resonator during the thermal cycles shown in Fig. 6.

7. Discussion

It is well-known that hydrogen contamination on niobium surfaces degrades Q. Our resonators might have absorved much of hidrogen on the outer conductor during electron polishing; It is impossible to remove hydrogen by heat treatments because of its composite structure made of niobium and copper. The hydrogen contamination would have degraded their Q values. If it does, we can attribute the gradual Q increase in the thermal cycles between 300 K and 4.2 K to a release of hydrogen from the surface into vacuum or the inside.

If the Q degradation after the round trip to intermediate temperatures is explained by a precipitation of normal conducting Nb-hydrides or weak superconductors as Aune et al.[14] and Roth et al.[16] proposed, how can we understand the Q increase during the slow cool-downs from the room temperature? Why did our resonators give good results in slow cool-downs, contrary to the experience at Saclay and other laboratories? Is the composite structure with niobium and copper related to the result? Answering these questions will need various experiments.

8. Conclusions

High accelerating field levels have been obtained since the drying method was improved to suppress adhesion of dust as a source of electron field emission. The twelve resonators surpassed the design accelerating field value of 5 MV/m with the rf input of 4 watts. Many of them had a field of around 6.7 MV/m, which gives an energy gain of about 1 MV for heavy ions of $\beta = 0.1$.

The values of Q were a little bit lower than expected value of 2×10^9. The Q degradation was partly attributed to the surface treatments and partly to the fast cooling rates. The good results with slow cooling rates is favourable in the on-line operation with refrigerators.

An apparent Q degradation happened after a warm up to the intermediate temperatures with our quarter wave resonator also. This phenomenon has become a common problem among superconducting rf cavities.

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