Progress in RF-Superconductivity for Heavy-Ion Acceleration at JAERI

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1. Introduction

For the JAERI heavy-ion booster project[1], we have been developing niobium superconducting quarter wave resonators(QWRs). A prototype QWR made of niobium and copper was fabricated in 1985-86. The result was reported in the previous(3rd) Workshop on RF Superconductivity at Argonne[2]. A maximum field level of 5 MV/m was obtained with the prototype resonator. Then, two units composed of two QWRs were respectively constructed in 1987 and in 1988. They are to be used as the buncher and de-buncher of the booster. As is described later in this paper, the field levels of the QWRs were 5 - 6 MV/m at a moderate rf input of 4 watts. The resonator performance has been improved along with the fabrication.

The booster linac will comprise forty QWRs and ten cryostats; four QWRs in each cryostat[3]. The fabrication of some resonators has started.

This paper describes the QWRs made for the buncher and de-buncher and their results.

2. Design of niobium quarter wave resonators

Forty-four identical QWRs of β_o = 0.10 and f = 129.8 MHz will be used in the booster. Four of them have been made for the buncher and de-buncher. The design of the QWRs is essentially the same as the prototype resonator reported previously at Argonne. It is illustrated in fig. 1. The center conductor is made of niobium, tapered, terminated with a drift tube of 70 mm in length, 90 mm in outer diameter and 30 mm in inner diameter and hollow for cooling with liquid helium. The maximum surface electric field on a round corner of the drift tube is 4.6 times the average field level along the beam axis. The outer conductor is made of niobium-copper composite materials and elliptical in holizontal cross section. One of the changes from the prototype one is that the outer conductors were made more flexible by adding grooves on their copper surface and by using demountable franges at their bottom in order to make it easy to tune the resonance frequency. The resonance frequency in operation can be tuned by pressing the outer conductor with a leverage mechanism and a stepping motor outside the vacuum[4]. An rf input capacitive-type coupler and a pick-up probe are put on the bottom end plate.

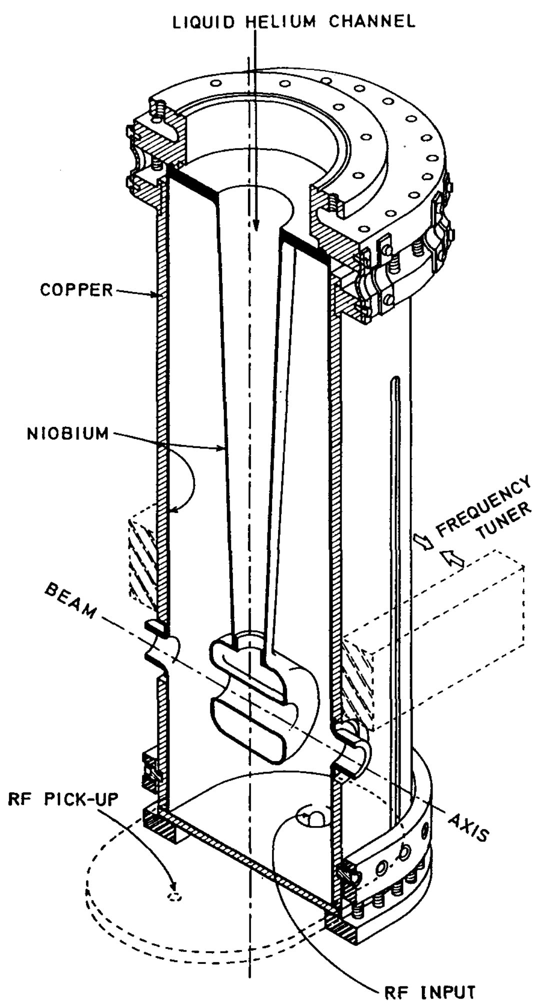

Fig. 1. A cut-away view of a superconducting quarter-wave resonator of β_o = 0.1 and f_o = 129.8 MHz.

3. Resonator fabrication

Niobium materials used for the QWRs were refined by multimelting process by an industry in Tokyo. Their RRR values were approximately 80. The fabrication was carried out by industries in Kobe. Similarly to the prototype resonator, the parts of the center conductors were cut out from solid niobium rods or plates and welded by electron beam welding. After the welding, the niobium surfaces were treated by machining, polishing and buffing. The center conductors were heat treated at 1000 °C for 6 hours in vacuum of 10^{-4} Pa after the welding and after the electropolishing. By the electro-polishing, a layer of 80 - 120 μm was polished off from the surfaces.

The outer conductors were formed by bending and electron beam welding from explosively bonded niobium copper composite sheets. The niobium surfaces of the outer conductors were similarly treated as the center conductors were. Heat treatment was done only for softening the materials after explosive bonding.

Coarse frequency tuning was inserted in the welding process. After the center and outer conductors were completed separately, they were welded together at the top end of the outer conductor with electron beams from outside.

After the final welding, thin surface layer of 10 to 30 μm was electro-polished from the resonator surface and it was succeeded by rinsing with deionized water, HF and 10% H_2O_2. The resonators were finally rinsed by spraying deionized water of 18 MΩcm, dried by blowing filtered nitrogen gas and assembled in a clean booth of class 1000.

4. Off-line test

The four QWRs were tested in a testing cryostat. The magnetic field level in the cryostat was suppressed to about 2.5 μT by a magnetic shield in order to prevent frozen-in magnetic flux. The Q-E_a curves measured at 4.2 K are shown in fig. 2, which were finally obtained after the following conditioning.

For the first rf input to the resonators at 4.2K, multipactoring occured at low field levels mostly between 0.1 to 0.2 MV/m. The

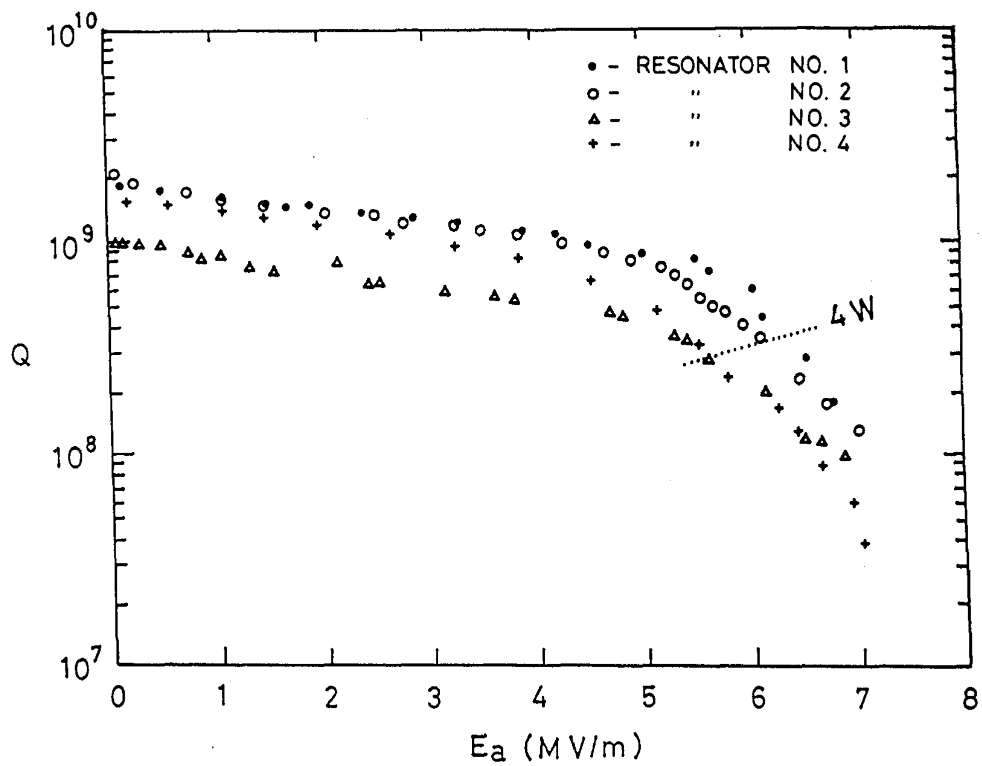

Fig. 2. Resonator performances measured at 4.2K after conditioning.

multipactoring barriers were overcome normally in 30 minutes by an over-coupled cw rf input from a 100 watts amplifier. A typical Q-E_a curve obtained after the conditioning is shown by curve A in fig. 3. The Q started decreasing at a field level around 4 MV/m due to the electron field emission. It is noticeable that, even with the strong field emission before powerful conditioning, the field level of about 5 MV/m was obtained with a moderate rf input of 4 watts.

The resonators were processed first by rf pulse conditioning without helium gas using 1.2kW rf amplifier. The pulse width and period were approximately 5 mS and 0.5 S, respectively. After several sharp discharges were observed, peak field levels reached 8 to 10 MV/m in the pulse operation. A Q-E_a curve measured after a 30 minutes pulse conditioning is shown by the curve B in fig. 3.

Second, the resonators were processed by helium conditioning for an hour. The helium pressure was 3 x 10^{-3} Pa. The rf pulses were similarly supplied as in the previous rf conditioning. A Q-E_a curve after the conditioning is shown by the curve C in fig. 3. After such conditioning, field levels improved to about 6MV/m at the rf input of 4 watts and about 7 MV/m at the thermally stable limit of about 20 watts.

The Q-E_a curves in fig. 3 were obtained for one of the two buncher resonators. The curves for the other one were very similar to them. For the two resonators of the de-buncher, some instability was found immediately after the conditioning. The conditioning was repeated a few times more to obtain the stable curves shown in fig. 2. This instability should be investigated in near future.

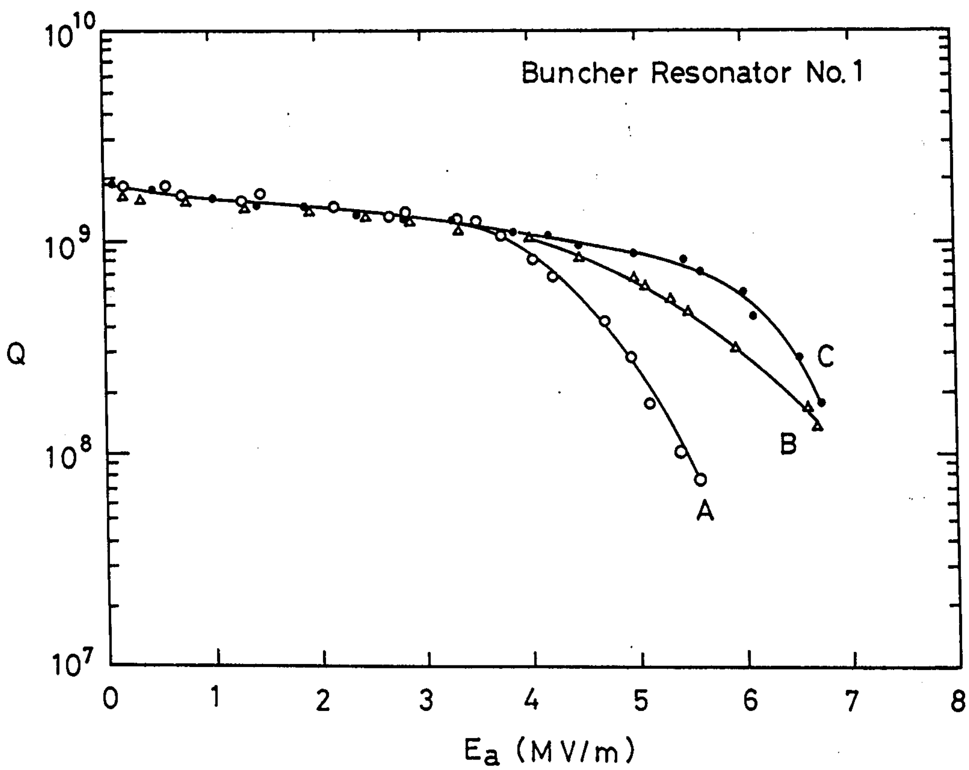

Fig. 3. Q - E_a(accelerating field) curves of a QWR measured after multipactoring conditioning(curve A), after high power rf pulse conditioning(curve B and after helium conditioning(curve C).

5. Beam test

One of the resonators was tested with 164 MeV(β = 0.1) Cl^{10+} beams[4]. The cryostat, which was for the buncher, was not equipped with magnetic shields. The field level of 5 MV/m was obtained with an rf loss of about 4 watts without helium conditioning. From the energy spectra of the beams through the resonator, the resonator field levels measured in the off-line tests were found to be accurate within the error of 2 %. The energy content obtained from the beam test was 0.046 - 0.048 $J/(MV/m)^2$, while the value obtained from the field mapping using a bead is 0.046 $J/(MV/m)^2$. An experiment of bunching was also done and the result was satisfactory.

6. Slow tuner

A tuner composed of a leverage mechanism, a screw, a set of worm gear and link shafts to a rotation feedthrough[4] was tested with a resonator. The frequency was able to be changed in an accuracy of 1 Hz. The tuning performance is good enough to stabilize the resonator phase and amplitude in the direct phase feedback loop with a moderately over coupled rf input. A measured phase stability with a phase controller was within 0.2°.

7. Cryostats

The cryostats are vertically cylindrical vacuum chambers with liquid helium dewars and heat radiation shields[1]. Resonators are suspended from the dewars. We decided to use cold helium gas from helium refrigerators to cool the heat radiation shields. Two prototype cryostats have been built, which will be used for the buncher and the de-buncher. Their magnetic shields of high u metal sheets put on the heat shields did not shield the resonators satisfactorily from the terrestrial magnetic field. Magnetic shields are not so important for the buncher or the de-buncher because the operating field levels are not so high. An alternative way of shielding is, however, being investigated for the ten cryostats of the linac.

8. Improvements for the linac resonators

Frame-work of the resonator fabrication has been established. The details are, however, to be improved further for the construction of 40 QWRs of the booster linac. The values of RRR were raised in its specification. Those of the materials already made for eight resonators were mostly between 85 and 110. Fabrication techniques are being improved for mass production in the industry. The most difficult point in the fabrication is the welding of confronting niobium ends of niobium-copper composites. The way of getting better uniformity of their thickness is being pursued for that problem. Parameters of explosive bonding were changed for it also: The waves on the boundary of niobium and copper were made smaller in size to as small as 50 μm in hight. The electro-polishing will be also improved for mass production. The temperature and time in the heat treatment will be changed toward better conditions. The rinse and drying processes are to be investigated and to be established for mass preparation.

References:

1) S. Takeuchi; "Status Report of JAERI Activities", elsewhere in this proceeding.

2) S. Takeuchi, Proc. of 3rd Workshop on RF Superconductivity, Argonne (1987)p429.

3) S. Takeuchi, T. Ishii, H. Ikezoe and Y. Tomita, to be published in Nucl. Instr. and Meth. A; Proc. of 5th Int. Conf. on Electrostatic Accelerators and Associated Booster, Strasbourg-Heidelberg (1989).

4) S. Takeuchi, T. Ishii and H. Ikazoe, to be published in Nucl. Instr. and Meth. A.