STATUS OF THE SUPERCONDUCTING HEAVY-ION TANDEM-BOOSTER LINAC AT JAERI

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Abstract

An independently phased superconducting linac has been used over four years as the heavy ion booster for the JAERI Tandem accelerator at Tokai since its completion in 1994. This report describes the status of the resonator performances, especially the relief of Q degradation of hydrogen-polluted resonators by applying a sequential fast precooling method and other possible methods. A big air leak which happened to cold resonators is also reported.

1 INTRODUCTION

The superconducting heavy ion booster for the JAERI Tandem accelerator at Tokai is an indepependently phased linac composed of 46 superconducting quarter wave resonators, which are made of solid niobium and niobium-clad copper, and all of which optimum velocities are 0.1c[1]. There has been no resonator troubles resulting in cryomodule opening since the completion in 1994. Heavy ions of Ni, Ge, Se, Zr, I, Au and etc from the 20UR folded type pelletron tandem accelerator were boosted at accelerating fields of 3 - 5 MV/m per resonator and transported to the targets for experiments of nuclear or solid-state physics.

We have a problem called *Q-disease* that the resonators in the first four linac cryomodules suffer from hydrogen Q-degradation, which is due to significant hydrogen absorption during the electro-chemical surface treatment and precipitation of hydrides on the resonator surfaces during slow pre-cooling by the cryogenic system. A sequential precooling method was applied to the resonators to increase cooling rates across the temperatures from 130K to 90K in order to suppress the Q-degradation.

Recently, a big air leak happened in the linac due to a beam hit. This paper mainly reports the results of the fast precooling and the air leak accident. Our efforts to extract hydrogen from the niobium walls are also reported.

2 RESONATOR PERFORMANCES

2.1 Recovery of Q by Fast Precooling

We found that a severe Q-degradation happened to a resonator after it was cooled taking a long time between 130K and 90K[2]. The cooling rate of 10 -12 K/h by the cryogenic system is too slow and should be increased to 20 -40 K/h in order to moderate the Q-degradation. Fortunately, the cold helium gas was designed to flow into the cryomodules in parallel. The helium flow could be concentrated to a few cryomodules while the resonators in them were cooled down across the precipitation zone of 130K to 90K, and sequentially switched to others.

The first four linac cryo-modules which contain the resonators ill of Q-disease belong to seven cryo-modules cooled by a cryogenic system. We tried two modes of a three-modules-by-three-modules sequence and a two-modules-by-two-modules sequence. The cooling rates obtained by the two modes were 17 -27 K/h and 21-48 K/h, respectively. The reason that the rates were spread wide is that the four resonators are cooled in series in a cryo-module.

The low-field Q values of the 20 resonators measured after the two precooling modes as well as the normal precooling mode are shown in Fig. 1. Resonators of no.1 to no.16 are the ones in the first four cryomodules. The Q values were recovered to 65 - 80 % of the off-line test results by the two-modules-by-two-modules mode, except the two severely sick resonators no. 2 and 4. Those two resonators may need a treatment of hydrogen outgassing to recover satisfactorily.

Figure 2 shows the accelerating field gradients of the first 20 resonators measured at rf input of 4 watts after normal precooling in 1995 and after the two-modules-by-

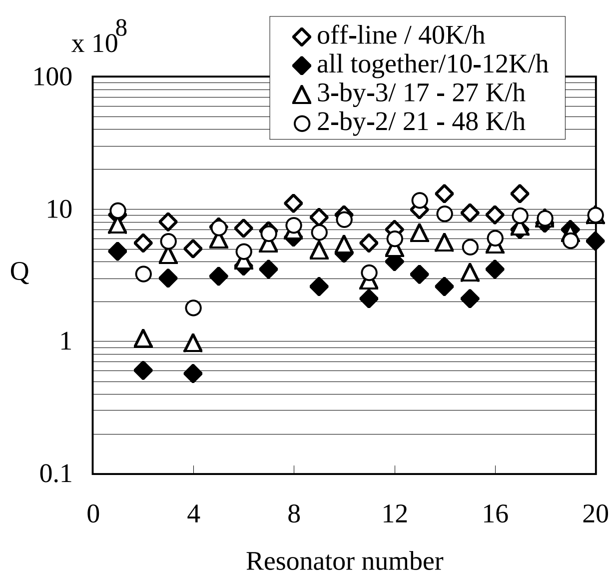

Fig.1 Low field Q of the first 20 resonators measured after four different precooling rates across the range of 130K to 90K; in the off-line tests, after the normal all-together precooling mode and after three-by-three and two-by-two sequential precooling modes.

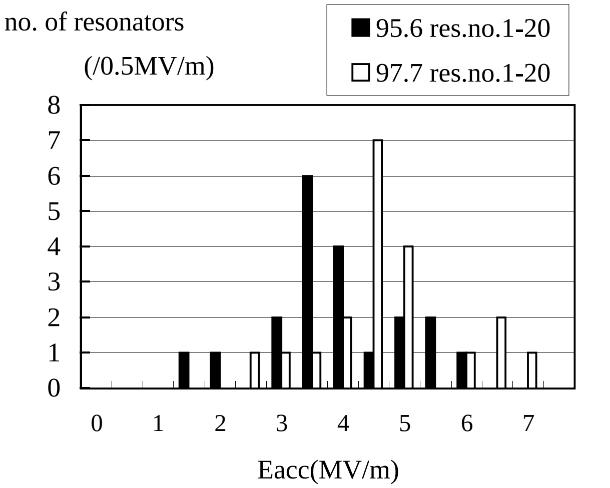

Fig.2 Histograms of the field gradients at rf input of 4 watts of the first 20 resonators measured in June, 1995 after normal all-together precooling mode and July, 1997 after three-by-three module sequential mode.

two-modules mode sequential precooling in 1997, as a histogram. The mean of the field gradients was recovered from 4.1 to 5.0 MV/m associated with the Q recovery.

The other 20 linac resonators which belong to the other cryogenic system have Q values between 0.6 and 1.2×10^9 so that the sequential precooling was not applied to them. In Fig.3, the accelerating field gradients of all the 40 linac resonators at 4 watts were shown as a histogram, which were measured at the same time together with the first 20 resonators. The overall mean value was 5.4 MV/m so that the originally designed value of 5 MV/m was attained.

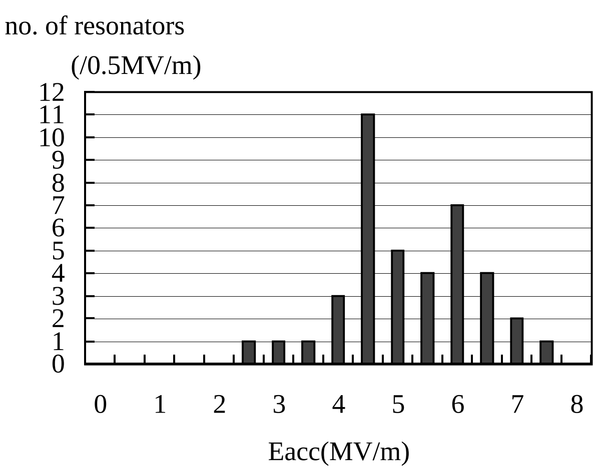

Fig. 3 Histogram of the field gradients of all the 40 resonators in the linac measured at rf input of 4 watts in July 1997.

2.4 Resonator Performances after Air Leak

A big air leak happened to the bellows between the first two cryo-modules on Sunday, May 31, 1998. The resonators were cold. The leak continued for about 12 hours untill the resonators were warmed across 80K. The pressure in the two cryostats were in the range of 10^{-1} Pa. The liquid level and helium pressure in the dewars were fortunately stable. The increase of the heat flow into the cryogenic system was about 23 watts, which was smaller than the refrigeration capacity per cryo-module of 28 watts. The resonators were once warmed up to the room temperature. The bellows had pin holes which seemed to be made by a sharp beam of 180MeV $^{32}S^{11+}$ of about 1 eμA. The leak rate measured later was 17 ml/s. Only from this rate, a lot of gas, as much as 1 kg, is supposed to be deposited on the cold surfaces of the resonators, the dewars and etc. From an additional fact that a big increase of leak rate have occured during the warming-up process, the deposition might be an order of 0.1 kg.

The accelerating field gradients of the resonators in the first two cryomodules are shown in Fig.4, in comparision with the data obtained before the leak(The sequential precooling was not applied to that machin time period, because of no demands for very high energies). The degradation of the resonator performances was not appreciably heavy, fortunately. They did not need heavy rf processing after the cool-down, either. It seemed that the niobium resonator surfaces were well protected from the gas deposition by the outer cans which have only two small beam holes of 25 mm in diameter.

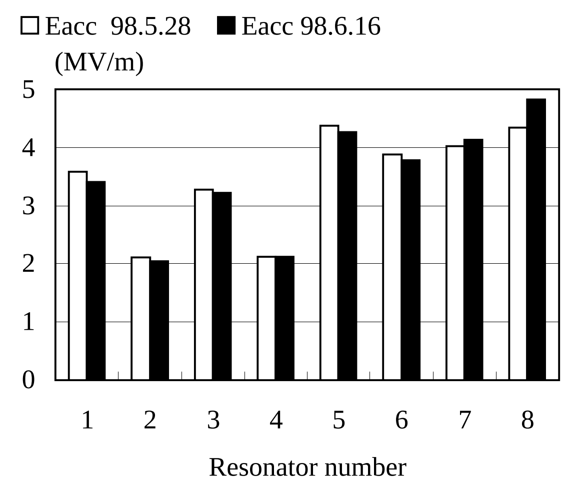

Fig. 4 Field gradients at rf input of 4 watts measured before and after an air leak trouble for the resonators on which air was deposited.

3 HYDROGEN OUTGASSING

It is idal to extract hydroden from the niobium walls by warming them up or by other methods if possible in order to cure the Q-disease. The quarter wave resonators are composed of a center conductor made of only niobium and an outer conductor made of niobium and copper and both conductors are welded together. It is, at least, possible to partially heat up only the center conductor.

3.1 Partial Heat Treatment

A spare resonators which was also ill of Q-disease was used to test the partial heating of the center conductor. A heater of 1.5 kW was set inside the center conductor, of which space is evacutated to 10^{-3}Pa. The top of the resonator was cooled by water. Lower 1/2 - 2/3 part of the center conductor was warmed up to about 600°C and hydrogen of an order of $1x10^{-3}$ mol was outgassed, which corresponded to a decrease of hydrogen content of 1 - 2 wppm in the niobium. The low field Q value measured after a slow precooling at a rate of about 12K/h was increased from 1×10^8 to 3.3×10^8 and the accelerating field gradient at 4 watt rf input from 2.7 MV/m to 4.0 MV/m. It looks worth applying this heat treatment to heavily hydrogen-polluted resonators such as the ones no.2 and 4.

3.2 Plan of ECR Plasma Surface Treatment

A method of hydrogen extraction without heating is wanted for the resonators made of bi-metals. Any of our attempts resulted in vain. Our next attempt is a plasma surface treatment utilizing electron cyclotron resonance at a micro-wave frequency. Gaseous elememts such as hydrogen, carbon and oxigen can be sputtered chemically from the surface[3]. We expect this method as a dry method of surface treatment for the superconducting niobium structures; that is, as a final surface treatment of rf superconducting cavities in place of heat treatment or high pressure water rinsing, or as a non-chemical surface re-processing method in case of heavy pollution.

A conceptional plan is illustrated in Fig.5. The ECR condition will be a frequency of 2.45GHz and a magnetic field of 0.09T. A resonator is co-axially placed in a solenoid. Investigations will be made with hydrogen, helium, oxigen or nitrogen gas.

4 OTHERS

4.1 Resonator control

Every resonator is controlled in a strongly coupled self-excited loop with phase lock and amplitude feed back functions. Six control modules made by Applied Superconductivity Inc. are used, each of which can control eight resonators. The rf power amplifiers were recently tuned up from 100 watts to 150 watts and moved close to the cryomodules in order to improve the stability at high field gradients. The resonator control is working well on the whole.

4.2 Cryogenic System

The cryogenic system is divided into two identical systems with refrigeration power of 250 watts. They have been working well except valve control troubles. The proportional valves are pneumatically driven and sometimes did not open as demanded. So that, an operator must make sure when time comes in a precooling period.

4.3 Beam Transport

The beam transmission was 40 - 100 % from the expectation in the past. After mis-alignment of 0 - 2 mm was found and fixed, the transmission was improved to about 80 - 100 %. An improvement was also given to the nine quadrupole doublet lenses placed between the cryomodules. They have now alternative focusing(F)-defocusing(D) planes as FD-DF-FD-DF- - -. The first four of them and the last four of them are simultaneously controlled, respectively, and the center one is turned off because there should be a beam waist point near the position. It made beam handling easier.

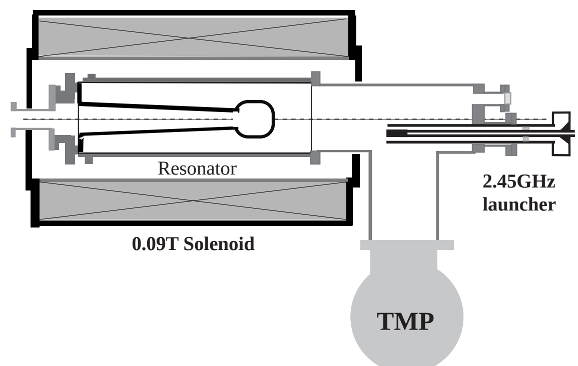

FIG. 5 Set-up plan of ECR plasma surface treatment for superconducting quarter wave resonators

5 CONCLUSIONS

The superconducting quarter wave resonators in the JAERI tandem superconducting booster have a mean field gradient of 5.4 MV/m, which is higher than the designed acceptance value of 5 MV/m, at the rf input of 4 watts, after carrying out the sequential fast precooling for the first 20 resonators. Resonator performances were found to be stable against a big air leak. Effective methods of hydrogen extraction from niobium are being investigated.

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