The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan 1993

DEVELOPMENT OF THE JAERI TANDEM SUPERCONDUCTING BOOSTER

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A superconducting booster composed of 46 superconducting quarter-wave resonators is being developed for the tandem accelerator at JAERI, Tokai. Resonators for the linac part had an accelerating field gradient of about 7 MV/m in average at an rf input of 4 watts in off-line cryogenic rf tests. The booster is equipped with two liquid helium refrigerators. On-line rf tests have been done with some of the resonators. This paper describes an outline of the booster and the results obtained in the development.

Introduction

Various heavy ion beams of proton to bismuth have been accelerated by the tandem accelerator at JAERI, Tokai scince 1980. Ion beams with a mass number below about 70 from the tandem can induce nuclear reactions with similarly heavy target nuclei. This booster project was planned in order to lift the limit toward bismuth.

An advantage of using superconducting resonators lies in providing high accelerating fields in cw mode with low power consumption. This fits well to our tandem booster, generally because high quality dc beams are available from a tandem accelerator. We designed a linac composed of 40 quarter wave resonator(QWR)s made of niobium and copper, of which rf phases are controlled independently.

The project started in 1984 with making a prototype niobium QWR. The prototype resonator was built successfully after overcoming some difficulties and showed a promising result[1]. We built two prototype units composed of two QWRs[2]. The construction of the booster linac started in 1988. In 1993, the development entered the final stage to perform beam acceleration tests.

Booster structure

Resonator structure

The structure of 130MHz QWRs developed for the booster is shown in Fig. 1. The center conductor is tapered, terminated with a drift tube and made of niobium. It is hollow and cooled drirectly with liquid helium. The outer niobium conductor is an oval cylinder and backed with a thick copper layer which acts as a heat conductor between niobium and liquid helium in the top frange. The resonant frequency is 129.8 MHz. The optimum beam velocity is 0.1. The acceleration length is 0.15 m. The frequency can be tuned by pressing the outer conductor. A capacitive input coupler and a pick-up probe are put at the bottom.

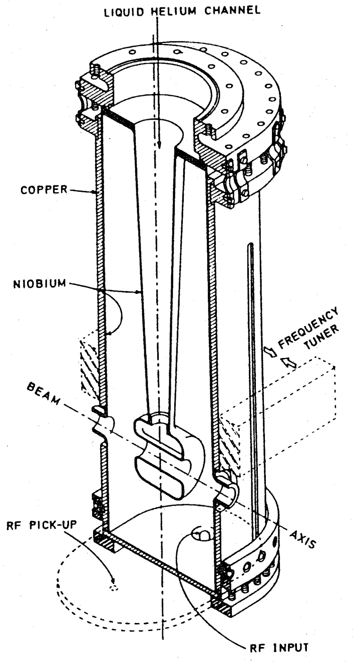

Fig. 1. A cut-away view of a superconducting quarter wave resonator

Accelerator structure

The layout of the booster is shown in Fig. 2. A double drift harmonic bunching system is placed about 10 m upstream of the linac. It is composed of two 130 MHz QWRs and two 260 MHz QWRs. One QWR for each frequency has enough power for bunching and the other one is the back-up. The distance between the two different frequency QWRs are set optimum to obtain a maximum bunching efficiency of about 60%. The linac is composed of 10 cryostat units. Each of them houses

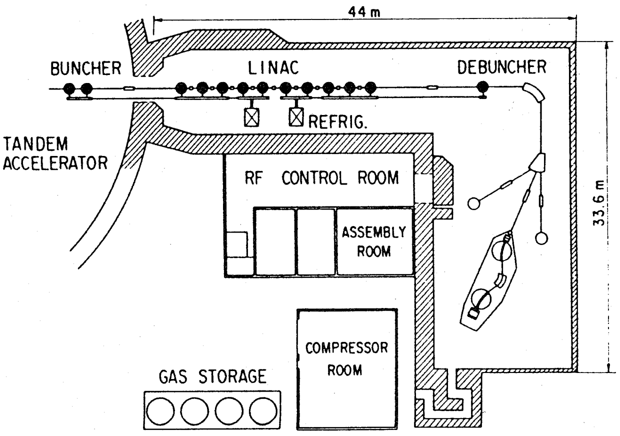

Fig.2. Layout of the JAERI tandem booster

four 130 MHz QWRs. All the 40 resonators have optimum beam velocity of 0.1. This choice is attributed to a wide velocity acceptance of QWRs. The transit time factor has a large value at a velocity higher than 0.05[2]. In all the spaces between the units, quadrupole doublets are placed.

Rf phases for the linac resonators are set to accelerate beams with moderate phase bunching and to leave, at the end of the linac, some energy dispersion neccessary for debunching. Accelerated bunched beams are longitudinally elongated by a drift of about 10 m and the energy dispersion is compressed by one or two 130 MHz QWRs in a unit that we call debuncher. The width of the debunched beams is expected to be about 1 nS. The beams are finally analyzed by a double focusing 90° magnet. Then, quasi-dc beams will be provided to the target room.

Resonator fabrication

In fabrication, niobium components cut out from rods and sheets are welded by electron beam welding. Niobium-copper composite sheets are explosively bonded, cut, bent to U-shaped halves and welded together between niobium and niobium and between copper and copper to form the outer conductor. The center conductor part is annealed in vacuum at 1000°C after electron beam welding. The niobium surfaces of the center and outer conducter parts are electro-chemically polished. Both parts are welded together after a degassing heat treatment of the center part.

After the fabrication in industries, resonator inside surface is elctro-chemically polished by about 10 μm, rinsed well with de-ionized water and supersonic power and dried in a clean room. These final treatments are very important to the resonator performance.

For obtaining a high field, high RRR(residual resistance ratio) materials are preferable because of high thermal conductivity. The RRR values of the niobium used for our QWRs are between 80 and 200.

Resonator performance

Off-line performance

A typical Q-E_{acc} curve, resonator Q as a function of accelerating field gradient, among the data obtained in off-line tests for linac resonators is shown in Fig. 3. Compared with an old Q-E_{acc} curve obtained in early stage of the development[2], there is no sharp decrease due to electron field emission at high fields. The improvement of Q at high fields was brought by preventing dust particales from accumulating on the niobium surface in the final rinse and drying processes.

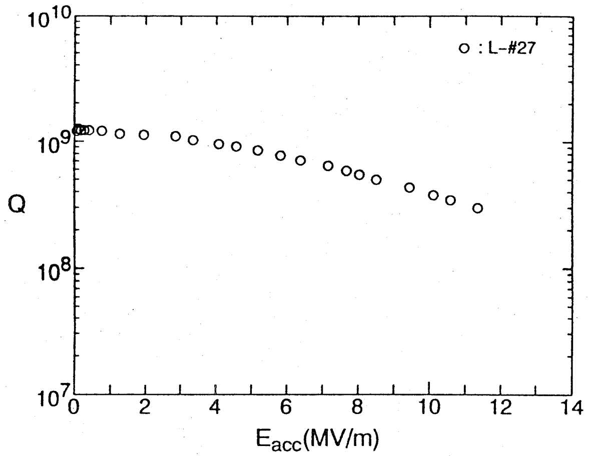

Fig. 3. A typical resonator performance.

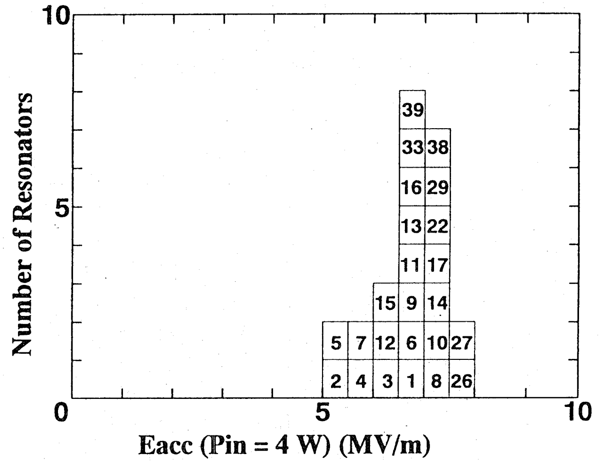

Fig.4. Distribution of accelerating field gradients at an rf input power of 4 watts. Numbers in the data are rsonator identification numbers.

A distribution of E_{acc} values at an rf input of 4 watts for the resonators tested in off-line is shown in Fig. 4. The average is about 7 MV/m. This corresponds to an acceleration of 1 MeV per charge for optimum velocity beams and means that the total acceleration voltage of 40 MV is achievable with 40 resonators. Maximum field gradients of higher than 10 MV/m were obtained with many resonators by increasing input power.

Q-degradation

A serious problem of superconducting resonators, called Q-degradation in thermal cycles, was found in recent years at many laboratories[3]. It was found for our resonators also. It was caused by a long elapsed time in an intermediate temperature zone in precooling before measurement at 4.2K. The Q-degradation zone was between 130K and 90K in our case. Fig. 5 shows our result of experiment. It is believed for the reason that hydrogen in niobium precipitates as a form of normal conducting niobium hydride on the niobium surface as a result of saturation of hydrogen solubility at the temperature. A high RRR material has a heavy degradation because of less trap centers of C, N or O. To avoid a serious Q-degradation in on-line performance, we should cool down the resonators quiker than a rate of 10K/h over the Q-degradation zone.

Beam diagnostics

For transverse beam diagnostics, profile monitors are installed at beam waist points, between the two bunching units, in front of the linac, at the middle

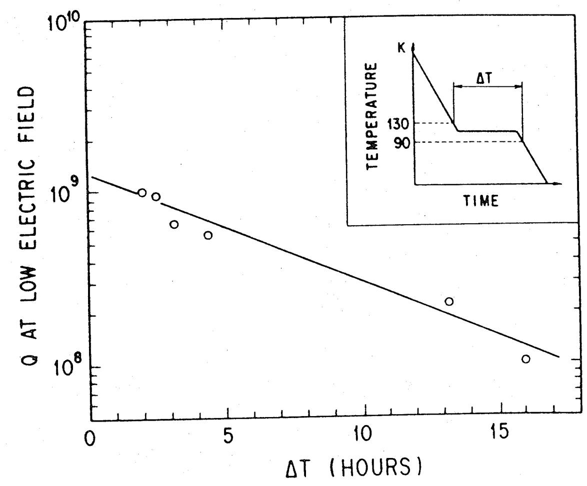

Fig. 5. Q-degradation on cooling between 130 and 90K. Q values at low electric field are plotted against the holding time between 130K and 90K. These data were obtained with resonator No.3 for the linac. The cooling scheme is shown in the inset.

point of the linac, at the exit of the linac and at the object and image points of the analyzing magnet.

For longitudinal beam diagnostics, energy-time detectors composed of Au target foils and silicon detectors are placed in front and at exit of the linac. The energy and time spectra are displayed two dimensionally on a CRT. The rf field levels and rf phases of the bunching resonators can be set by seeing the display from the front detector. Energy gains by linac resonators can be measured with the exit detector.

For setting rf phase of linac resonators, three beam bunch phase detectors are put after the 3rd, 6th and 10th linac units, which are normal conducting QWRs with Q of about 2000. They are excited by beam bunches and output signals of 5 - 10 μV/nA can be taken out. The time of beam flight from a resonator being tuned is measured as a phase difference between the signal and the reference rf signal. It varies as a function of resonator phases so that the resonator phase can be set by knowing zero crossing points and peaks of the measured curve.

Cryogenics

As is shown in Fig. 2, the booster is equipped with two refrigerators. Each refrigerator has a refrigeration power of 250 watts for liquid helium loop and 1,500 watts for 80 K gaseous helium loop. The 80 K loops are used for radiation shielding of the resonators and liquid helium transfer lines. No liquid nitrogen is used for the cryogenic system. Helium output from each helium compressor is 1,420 Nm^3/h(70 g/s). Each compressor is driven by a 310 kw motor. Each unit has two 30 m^3 buffer vessels.

The liquid helium loop branches in valve boxes in the main transfer line. Each branch line starts from a remote controlled valve, passes through precool heat exchangers on four resonators, enters the liquid helium vessel, and returns to the main transfer line. There is no liquid helium storage vessel outside the cold boxes or cryostats.

The designed refrigeration powers have been confirmed. The systems are automatically operated by programs. The radiation shields are precooled to 150 K first. In a test run, precooling of the resonators took about 32 hours, and liquid filling took about 12 hours.

On-line performance

Sixteen resonators have been preliminarily tested in on-line. Cooldown rates over the Q-degradation zone with the both refrigeration systems were about 10K/h. It might cause a Q-degradation. The results split into two groups depending on the time that the surface treatments were done. Five resonators treated recently had no definite degradation(Group 1). Seven resonators treated a few years ago and four resonators treated several years ago had a degradation of 30 to 70%(Group 2). A possible explanation for this result lies in our recent electro-chemical polishing technique which is for Group 1; we made an improvement to let out hydrogen gas generated in the electro-chemical polishing solution by using nitrogen gas bubling. Resonators in Group 2 seem to be contaminated with hydroden in electro-chemical polishing heavy enough to cause a Q-degradation. Otherwise, the resonators might not be kept in good condition. For further discussion or finding a solution to avoid a severe Q-degradation, further investigation is wanted.

References

[1] S. Takeuchi,"Status of Work on Superconducting Quarter Wave Resonators at JAERI," in Proceeding of the Third Workshop on RF Superconductivity, 1988, pp.429-434.

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[3] (for example) B. Bonin, R. W. Röth, "Q-Degradation of Niobium Cavities Due to Hydrogen Contamination," Proceedings of the 5th Workshop on RF Superconductivity," 1991, pp.210-244.