SUPERCONDUCTING RF ACTIVITIES AT JAERI

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Abstract

Japan Atomic Energy Research Institute (JAERI) has three groups working on the superconducting RF application to accelerators; superconducting proton linac, superconducting heavy ion booster linac and superconducting driver for FEL. Superconducting proton linac is being designed and developed for the JAERI/KEK Joint Project. Tandem booster for heavy ion acceleration and FEL driver for electron acceleration are in operation.

1 SUPERCONDUCTING PROTON LINAC

Japan Atomic Energy Research Institute (JAERI) proposed the Neutron Science Project (NSP) for neutron science, nuclear physics, neutron irradiation and RI beam science and the engineering study of nuclear waste transmutation[1]. The accelerator for the NSP consisted of a 1.5-GeV proton linac and two storage rings. The maximum beam power was intended to be 5 MW. Superconducting structure was chosen for the high energy part of the linac from 0.1 to 1.5 GeV[2]. High Energy Accelerator Research Organization (KEK) also planned the Japan Hadron Facility (JHF) for neutron science, muon science, exotic nuclei science, fundamental particle physics and neutrino oscillation experiments[3]. The JHF accelerator consisted of a 200-MeV linac, a 3-GeV rapid-cycling synchrotron (RCS) and a 50-GeV synchrotron.

These two projects had some common features in their purposes. In 1999, JAERI and KEK agreed each other to merge these projects into the Joint Project to take more effective promotion of the scientific and engineering fields[4].

Figure 1 shows the schematic layout of the accelerator for the Joint Project. It consists of a 600-MeV linac, a 3-GeV RCS and a 50-GeV synchrotron. Slowly extracted 50-GeV beams will be used for the experiments of both fundamental particle physics and nuclear physics in the 50-GeV experimental area. The fast-extracted beams will be used for the neutrino oscillation experiments. 3 GeV beams will be used for the experiments of neutron science, muon science and exotic nuclei science in the 3-GeV experimental area, as well as for the injection to the 50-GeV synchrotron. R&D studied for the nuclear waste transmutation will be performed with 600 MeV beams from the linac.

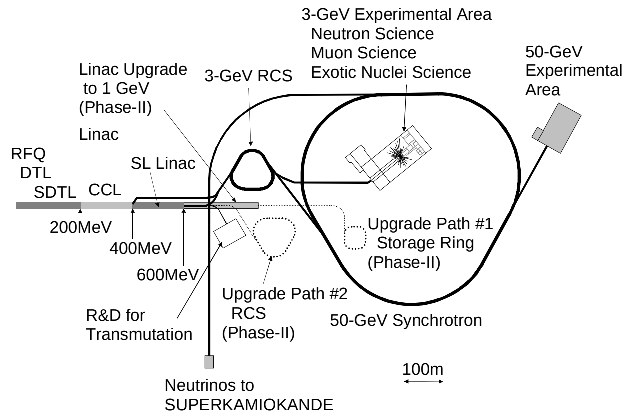

Fig. 1 Schematic view of the Joint Project

The project is divided into two phases. In Phase-I, beam power of 1 MW will be achieved at the 3-GeV RCS output in 2005. In Phase-II, the beam power will be increased to 5 MW for the pulsed spallation neutron experiments, which is the final goal of the project. It will be achieved with full-energy linac (1 GeV) and storage rings (upgrade path #1). Other upgrade path is also considered for Phase-II; upgrade the energy and beam current of the RCS and install one more RCS (upgrade path #2).

The linac for Phase-I comprises a negative ion source, a 3-MeV RFQ, a 50-MeV DTL, a 200-MeV SDTL (separated type DTL), a 400-MeV CCL and a 600-MeV superconducting linac (SCL). Frequencies of low energy part (RFQ, DTL and SDTL) and high energy part (CCL and SCL) are 324 MHz and 972 MHz, respectively. It is planned that 400 MeV beams are injected to the RCS at first, and SCL provides beams to the R&D for transmutation. In this period, beam study for the SCL will be carried out and then 600 MeV beams will be injected to the RCS.

Conceptual design and R&D are in progress in JAERI and KEK. The current R&D work is done with the 600 MHz cavity for the NSP. The R&D target is being shifted toward the Joint Project on the basis of the current R&D achievements. System design, cavity development and dynamic analysis of Lorentz detuning are reported in a poster (WEP020). Mechanical property at cryogenic temperature and R&D for the HOM coupler are reported in posters TUP042 and WEP003, respectively.

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2 SUPERCONDUCTING HEAVY ION BOOSTER LINAC

2.1 Present status of the superconducting heavy ion booster linac

The superconducting heavy ion linac at JAERI Tokai has been working satisfactorily as the post accelerator of the tandem accelerator. Forty 130MHz superconducting quarter wave resonators, which are used in the acceleration modules, have beta values of 0.1 and are made of niobium and copper-clad niobium, have been mostly operated at field levels between 3 and 5 MV/m. A fast precooling for relieving the Q-disease symptom which was found with some of the resonators[5] has not been applied to the operations for these years because of no strong demands for operations at the highest field gradients of the resonators. No acceleration module has been opened ever since because of no troubles with the resonators. Only a buncher unit was opened recently to recover from a small leak which happened at a low temperature.

2.2 Surface cleaning by ECR plasma discharges

With respect to the development work on superconducting RF technology at the tandem-booster accelerator facility, a surface cleaning of niobium surfaces, which is a dry method utilizing ECR plasma discharges, is being investigated by using a spare resonator, a microwave of 2.45GHz and a solenoid of 0.09T. A healing effect of the Q-disease was observed after the long plasma discharges described below.

The set-up for ECR plasma cleaning is illustrated in Fig. 2. The magnetic field in the solenoid is as uniform as 5% over the resonator space. The gases used up to now were hydrogen, helium, water vapor and oxygen. All of the gases were discharged at a gas pressure of 2-3×10^{-3} Pa. The RF power of 100 W to 300 W was fed into the resonator. The resonator was air-cooled. The magnetic field and RF coupling were tuned to the plasma.

The result is shown in Fig. 3. The Q values were always measured after fast(at a rate of about 40 K/h) and slow(10-12 K/h) precoolings over the precipitaion temperature range from 130K to 90K. Many treatments had been made with the resonator before this experiment. A CP treatment with mixing ratio of 1:1:4 (= HNO_3:HF:H_2PO_3) and an outgassing of the open end part of the center conductor, which is made of only niobium, at about 600ºC are additionally shown in the figure. A hydrogen discharge had an negative effect on the Q values. A helium discharge by 100 W RF input for 60 hours presented a positive result. A water vapor discharge which contains hydrogen and oxygen active atoms resulted in no effect. A discharge with oxygen for a relatively short time improved only the Q for slow precooling. As a result of ECR plasma discharges, helium and oxygen gases improved the Q of slowly cooled resonator by a factor of about 2 and the field gradient into the range of above 4 MV/m.

Possibility of hydrogen outgassing from bulk niobium has been investigated for ECR plasma discharges of various

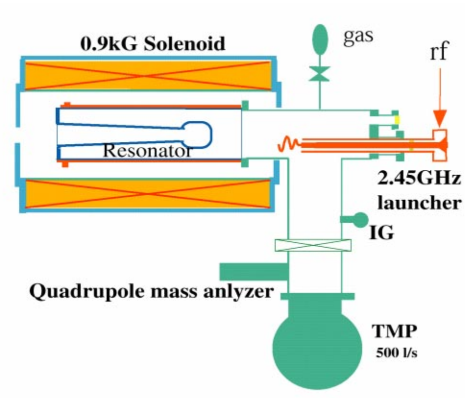

Fig.2 Set-up of ECR plasma cleaning for a quarter wave resonator

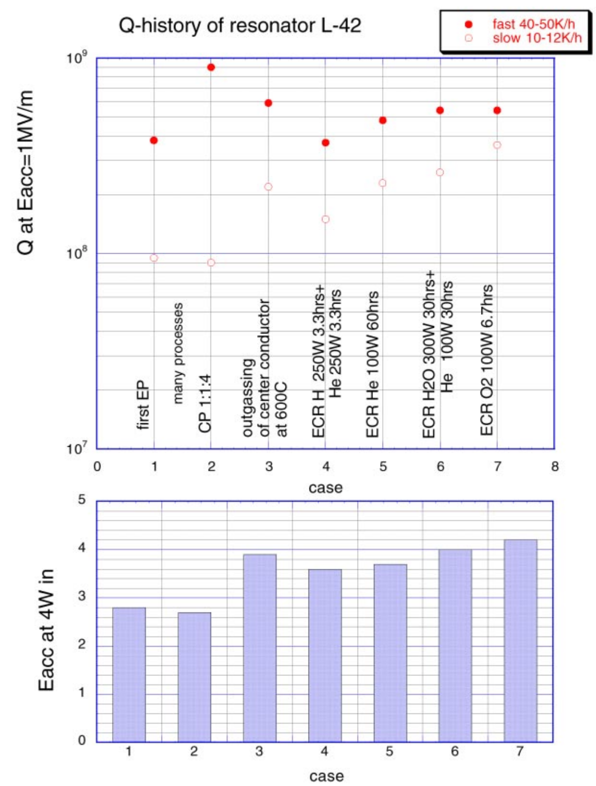

Fig. 3 Q and E_{acc} measured after ECR plasma discharges (case 4-7) including other previous treatments(case 1-3). Solid dots in the upper figure are the Qs at E_{acc} of 1MV/m, which were measured after fast precooling(at a rate of about 40 K/h) and open circles were those after slow precooling(at about 10 - 12 K/h) from 130 K to 90 K. E_{acc} in the lower figure were the values at RF input of 4 W for the slow precooling

gasses. We have not obtained any positive result, yet.

3 SUPERCONDUCTING ELECTRON LINAC FOR FEL

In February 1998, the JAERI FEL driven by a superconducting RF linac lased successfully to produce 0.1kW FEL light in quasi continuous wave operation of ~1 ms pulse length and ~10 Hz repetition rate[6]. The beam power was ~100kW. The light output power has been increased to 0.3 kW up to now. The superconducting electron linac consists of two single-cell cavities for pre-acceleration and two 5-cell cavities for main acceleration. The E_{acc} values of the 5-cell cavities are 5-7 MV/m in the lasing operation and the maximum value is 8.3 MV/m.

The present program goal of 1kW class light output will be achieved within these several months by improving the optical outcoupling method in the FEL optical resonator, the electron gun, and the electron beam optics in the JAERI FEL driver. We are also preparing beam recirculation loop to demonstrate beam energy recovery system. The beam test of the recirculation loop will begin in 2000.

We may summarize our recent activities and fruitful results in the following.

(1) Successful operation of the first superconducting RF electron linac in Asia.

(2) Successful operation and construction of the first all-solid-state RF system for an electron RF linac with a virtually infinite life span.

(3) Successful operation and demonstration of the world-largest recondensing 4K He4 refrigerators system.

(4) Successful realization and operation of the world-first modular and independent Zero-Boil-Off (ZBO) cryostat for the JAERI superconducting RF electron linac FEL driver.

(5) Successful demonstration of the first coupling-adjustable main antenna in the RF electron linac, and optimization of the power losses in the RF transmission system.

(6) Construction of the first shift- and deflection-compensated wedge pole hybrid undulator system.

(7) Successful realization one of the most precise and the quickest matching between twice of the optical resonator length with separate distance between two neighboring electron beam pulses.

(8) Successful demonstration of the world-first and largest recondensing 2K He3 refrigerators system.

(9) Successful demonstration of the world-strongest 0.1kW FEL oscillation in a quasi-continuous operation February 26th, 1998, and recent increase up to 0.3kW laser output.

(10) Successful operation of the 100kW-class electron beam output using the JAERI superconducting RF electron linac FEL driver.

(11) Successful operation of the 500MHz UHF band superconducting RF electron linac with accelerating gradient from around 5MV/m up to 8.3MV/m.

(12) Successful 24 hour- and one year continuous operation of the JAERI FEL cryogenic system with no maintenance and operation crew and specialist in 1996 Japanese fiscal year.

4 REFERENCES

[1] M. Mizumoto et al., “A High Intensity Proton Linac Development for the JAERI Neutron Science Project”, Proc. Linac98., Chicago, USA, (1998) in press,

[2] N. Ouchi et al., “Proton Linac Activities in JAERI”, Proc. 8th Workshop on RF Superconductivity, Abano Terme (Padova), Italy, p12 (1997)

[3] Y. Yamazaki, “ The Japan Hadron Facility Accelerator”, Proc. APAC98., Tsukuba, Japan, p314 (1998)

[4] Y. Yamazaki et al., “Accelerator Complex for the Joint Project of KEK/JHF and JAERI/NSP”, PAC99, New York, USA, p513 (1999)

[5] S.Takeuchi and M. Matsuda, “First Three Year Operational Experience with the JAERI Tandem-Booster”, Proc. 8th Workshop on RF Superconductivity, Abano Terme (Padova), Italy p237 (1997)

[6] E. Minehara et al., “A 0.1kW Class Operation of the JAERI Superconducting rf Linac based FEL”, Nucl. Instrum. Method. A429, p9 (1999)