# THE R&D STATUS ON THE FRONT END OF THE HIGH INTENSITY PROTON ACCELERATOR IN JAERI

K. Hasegawa, M. Mizumoto, J. Kusano, N. Ito, H. Oguri, Y. Touchi*, H. Ino** and K. Mukugi***
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki, 319-11, Japan
* Sumitomo Heavy Industries, Ltd., Niihama, Ehime, Japan
** Mitsubishi Heavy Industries, Ltd., Nagoya, Aichi, Japan
*** Mitsubishi Electric Corp., Kobe, Hyogo, Japan

**Abstract**

The R&D for the high intensity and high duty factor proton linear accelerator has been carried out. A hydrogen ion source, an RFQ and an RF power source have been developed and 2 MeV proton beam tests have been conducted to study the front end of the accelerator. In the beam tests, an accelerated current of 70 mA with a duty factor of 7 - 10 % was achieved. To demonstrate the high duty factor operation of the DTL, a hot test model was fabricated and high power tests with a duty factor of 20 % have been carried out. In this report, present status of the R&D activities is described.

## Introduction

A high intensity proton linear accelerator with 1.5 GeV and 10 mA has been proposed for basic research and to perform the various engineering tests for a nuclear waste transmutation system[1]. The low energy accelerator components have been developed since 1991 for the R&D, because the beam current and the quality are mainly determined by the low energy portion. Heat removal from the accelerator structures is one of the important issues for the high duty factor operation.

To study the front end of the accelerator, an ion source, an RFQ, and an RF source for 10 % duty factor operation were fabricated and 2 MeV beam tests have been performed. The characteristics of the RFQ such as beam current, energy spectra and emittance have been studied. To demonstrate the high duty factor operation and to study the cooling capabilities of the DTL, a hot model with 9 cells was fabricated and high power tests have been carried out.

## Beam Test of the 2 MeV RFQ

The RFQ is a four-vane type and the frequency is 201.25 MHz. It is designed to accelerate 100 mA (peak) of protons to 2 MeV with a duty factor of 10 %[2]. The low power tuning, the high power conditioning and the first beam test were carried out at the test shop of the factory and the basic performance was obtained[3]. To study further properties, the beam tests have been made at JAERI since November, 1994.

A multicusp type ion source has been developed to obtain a high brightness proton beam. The ion source has been operated successfully with more than the designed current of 140 mA at 100 keV[4]. The proton beam from the ion source is focused by the two solenoids (solenoid-1 and -2) to match to the RFQ acceptance in the Low Energy Beam Transport (LEBT). The output beam current of the RFQ is measured by a Faraday cup. Figure 1 shows a contour plot of the RFQ output beam current with two solenoids currents. There are mainly two matching data sets; the lower set ($I_{sol1}$=145A, $I_{sol2}$=200A) and the higher set ($I_{sol1}$=275A, $I_{sol2}$=220A). The higher set has a sharp peak as a function of solenoid-2 current and is sensitive to the various conditions such as the ion source and the LEBT. The maximum RFQ output current was 80 mA at the ion source extraction current of 155 mA. The transmission rate through the RFQ was estimated to be 70 - 80 %, given the ion source proton fraction of 70 %. The precise proton fraction in the input beam, however, was not clear due to the mass separation effects of the solenoids. Moreover, we had meltdown troubles with a Faraday cup just before the RFQ. To measure the input current and to evaluate the transmission rate, a current transformer system for 1 msec pulse width beam is now under test off-line and will be installed in the LEBT in a few months.

The energy of the proton beam from the RFQ was measured by a compact magnetic energy analyzer installed in the Medium Energy Beam Transport (MEBT). The pole

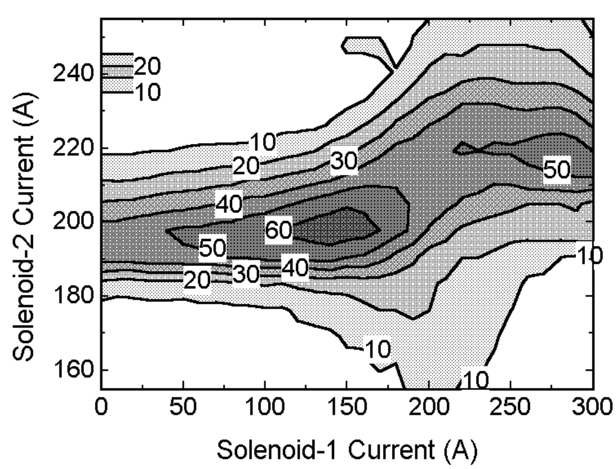


Fig. 1 Contour plot of the RFQ output beam current in mA as functions of the two solenoids currents in the LEBT.

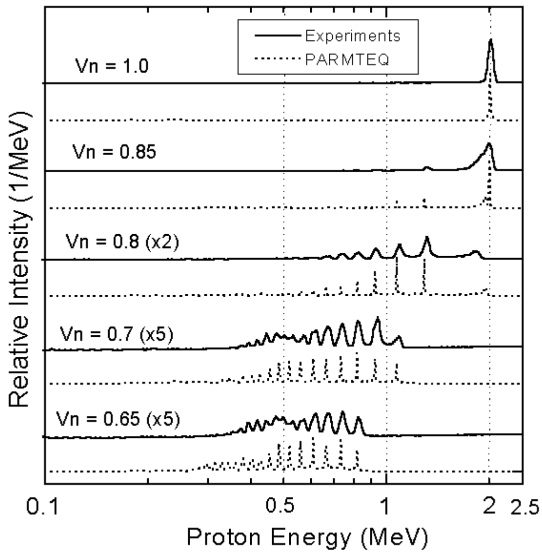


Fig. 2 Measured and simulated RFQ beam energy spectra. PARMTEQ results are arbitrarily normalized.

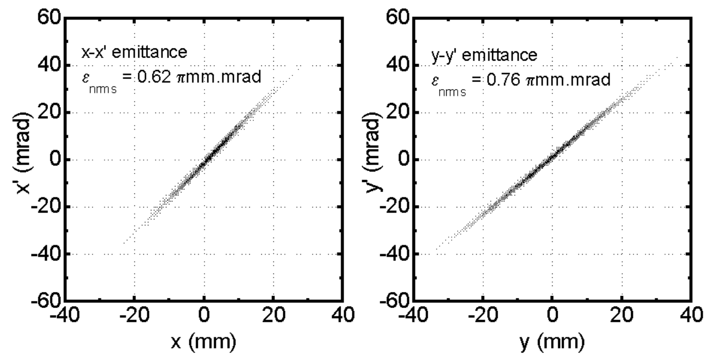


Fig. 3 Typical emittance diagram at 0.8 m downstream of the RFQ.

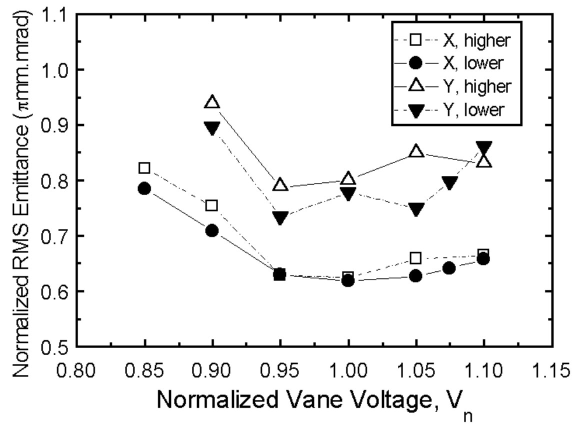


Fig. 4 Normalized transverse rms emittance for the two matching cases (higher and lower) as a function of vane voltage.

radius, the gap length and the deflection angle are 40 mm, 6 mm and 25 deg, respectively. The energy resolution is assumed to be 5 % for 2 MeV proton beam. Figure 2 shows beam energy spectra for five relative intervane voltages as well as the PARMTEQ simulated results. As the vane voltage is reduced, the energy spectrum shifts to the lower energy and many peaks are observed, which are in good agreement with the simulated results.

The RFQ emittance was measured by the conventional double-slit type monitor. The width of the front and rear slits and the distance between the slits were 0.4 mm, 0.1 mm and 380 mm, respectively. To prevent the meltdown of the front slit collimator, the repetition rate was limited to less than 2.3 Hz at 1 msec pulse width. Typical emitttance diagram and the rms emittance as a function of the normalized vane voltage are shown in Fig. 3 and Fig. 4, respectively. The magnitude of the emittance has a minimum point at around Vn=1, which corresponds to the designed vane voltage.

At the beginning of the beam test in JAERI, the maximum duty factor was limited less than 2 % due to the partial burn out of the RF contact at the RFQ. A silver plated spiral type RF contact, which is made of beryllium copper alloy, was used between the tank and the vane. The diameter of the contact was 3.2 mm and the thickness of the base beryllium copper alloy and the silver plate were 100 µm and 30 µm, respectively. To improve the heat transfer properties, it was replaced by a 100 µm thickness silver-plated type. In addition to the contact replacement, copper blocks were installed to cover the open space between the vane and the tank to reduce the heat dissipation at the vane end region. As a result of these modifications, steady operations with 7 % duty factor, and short-duration operation at 10 % duty factor can be achieved at the beam current of 70 mA.

## Development of the 1 MW RF System

A 201.25 MHz RF system was designed and manufactured for the RFQ beam tests and the DTL high power tests. A tetrode, 4CM2500KG (EIMAC), is used in a three-stage amplifier configuration[5].

Dummy load tests have been completed. An RF power output of 1 MW was achieved at a duty factor of 0.6 %. The power efficiency was 60 %, which is in good agreement with the designed value of 62 %. At high duty operation of 12 %, RF power of 830 kW was generated, which satisfied the requirement for the tests in the R&D.

The voltage and the phase stability during the beam acceleration should be controlled within +/-0.5 % and +/-1 deg., respectively. To satisfy these specifications, the RF control system has a feedforward-circuit combined with a feedfback-circuit. The performance of the feedback-circuit was examined in the RFQ beam tests. The amplitude and the phase errors were on the order of 0.5 % and 5 deg., respectively, during 100 µs period after the beam injection when the beam loading was 110 kW. The feedforward-circuit will be examined to compensate these errors.

## High Power Test of the DTL Model

A DTL hot test model with 9 cells, which is a mockup of the low energy portion of the DTL, has been fabricated to study the RF characteristics and the cooling requirements[6]. An electromagnetic quadrupole using a hollow conductor (5 mm x 5 mm) was designed for the focusing magnet, of which field is 80 T/m with 5.5 turns at 780 amperes. Two quadrupole magnets have been fabricated and installed in the model tank.

The high power tests have been carried out with the RF power source. Figure 5 shows the schematic layout of the test. Prior to the cooling requirement test, high power conditioning was done while monitoring the vacuum pressure and the RF signals from the pickup loop and the directional coupler. At first, the duty factor was limited to less than several percent due to the RF contact problem at the end plate. After covering the viton O-ring thoroughly to improve the RF contact, RF power with a duty factor of 20 % was fed to the model without troubles to 128 kW, which corresponds to the average axial field of 2 MV/m. Bremsstrahlung X-ray spectra from the gap were measured to estimate the gap voltage. The measured gap voltage was 195 kV at an RF power of 128 kW, which was in good agreement with the calculated value of 197 kV by the SUPERFISH code.

The measured RF heat dissipation power in the each drift tube and end plate was in good agreement with the SUPERFISH results. The frequency shift as a function of the #8 drift tube temperature also agrees well with the calculated values as shown in Fig. 6. The calculations were performed with the combination of the thermal deformation from the ABAQUS FEM code and the frequency shift from the SUPERFISH code. These high power test results have confirmed the heat dissipation calculation and the cooling design of the DTL.

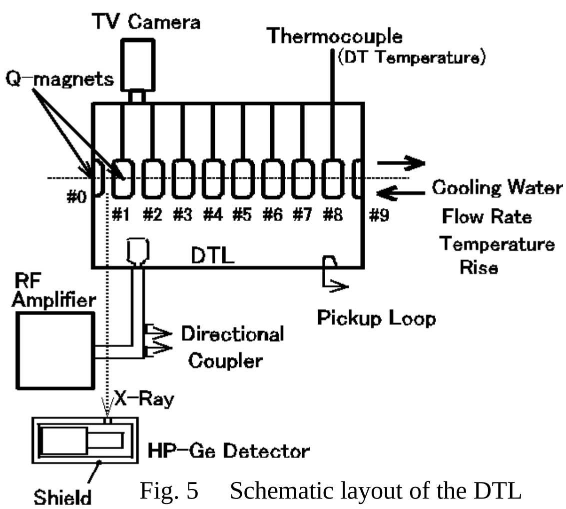


Fig. 5 Schematic layout of the DTL high power test.

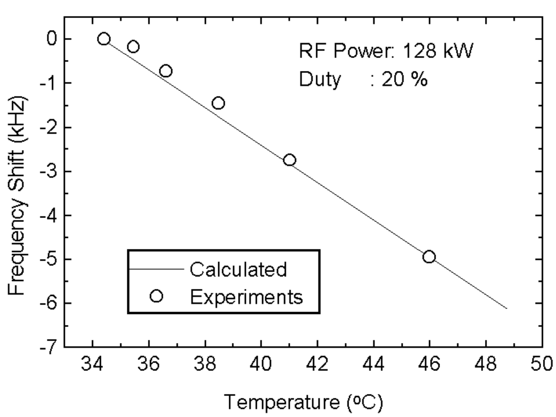


Fig. 6 Frequency shift of the DTL model tank as a function of the #8 drift tube temperature.

## Summary

R&D with the design and the fabrication of the prototype accelerator structures (ion source, RFQ, RF source and DTL) have been carried out. The good performance of the components has been confirmed. In the RFQ beam tests, acceleration current of 70 mA with a duty factor of 7 - 10 % has been achieved. The DTL high power test results have confirmed the heat dissipation calculations.

A superconducting (SC) cavity is one of the feasible candidates for the high-$\beta$ structures and its R&D work has been started[7]. For the injector of the SC cavities, much longer duty factor or continuous-beam operation will be required. Design work on the RFQ and DTL for the CW operation are being performed.

## References

[1] M. Mizumoto et al., "A High Intensity Proton Linac Development for Neutron Science Research Center", These proceedings, THP-08.

[2] K. Hasegawa et al., "Design Study on an RFQ for the Basic Technology Accelerator in JAERI", 1992 Linear Accelerator Conference, Ottawa, Canada, AECL-10728, pp.314-316 (1992)

[3] K. Hasegawa et al., "First Beam Test of the JAERI 2 MeV RFQ for the BTA", 1994 International Linac Conference, Tsukuba, Japan, pp.113-115 (1994)

[4] H. Oguri et al., "A High Brightness Hydrogen Ion Source for the BTA at JAERI", ibid., pp.381-383

[5] Y. Touchi et al., "An RF system for the BTA", Fourth European Particle Accelerator Conference, London, 1994, pp.1900-1902 (1994)

[6] N. Ito et al., "Fabrication and Tests of the DTL Hot Model in the R&D Works for the Basic Technology Accelerator (BTA) in JAERI", 1994 International Linac Conference, Tsukuba, Japan, pp.119-121 (1994)

[7] N. Ito et al., "Development of a Superconducting Cavity for the High Intensity Proton Linac in JAERI", These proceedings, THP-11.