FIRST BEAM TEST OF THE JAERI 2 MeV RFQ FOR THE BTA

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Abstract

The JAERI RFQ is a four-vane type radio frequency quadrupole designed to accelerate 100 mA (peak) of protons to 2 MeV with a duty factor of 10%. The RFQ is one of the main injector components for the Basic Technology Accelerator (BTA). Low-power rf tuning and high-power rf conditioning has verified the rf design features. The first proton beam test was successfully carried out in February 1994 and the acceleration current of 52 mA with a duty factor of 5% was achieved.

Introduction

A high intensity proton linear accelerator (ETA: Engineering Test Accelerator) with an energy of 1.5 GeV and an average current of 10 mA has been proposed for the accelerator-driven nuclear waste transmutation[1]. As a first step in the development, low energy portion of the accelerator (BTA: Basic Technology Accelerator) with an energy of 10 MeV and an average current of 10 mA is planned to be built. The JAERI 2 MeV RFQ[2] is one of the major accelerator components for the BTA.

Table 1 summarizes the RFQ design parameters and Fig. 1 shows the RFQ cavity. The RFQ was designed to accelerate 100 mA of protons with a duty factor of 10%. The RFQ was fabricated and assembled in 1993. After the low-power tuning and the high-power conditioning, the first beam test was carried out successfully in February 1994. The characteristics of the RFQ such as the beam current, transmission, energy spectrum and transverse beam profile were studied as functions of the input beam parameters (e.g., ion source acceleration voltage, input current, beam matching with solenoids) and of the rf power (RFQ vane voltage).

TABLE 1
RFQ Design Parameters

Ion	Proton
Frequency	201.25 MHz
Input/Output Energy	100 keV / 2.0 MeV
Beam Current	100 mA (peak)
Duty Factor	10 %
Number of Cells	181
Vane Length	334.8 cm
Cavity Diameter	36.6 cm
Mean Bore (r_0)	0.613 cm
Vane Voltage	113 kV (1.68 Kilpatrick)
Q-value(100%)	13260

Low-Power Tuning

After the mechanical alignment of the vanes, relative field distribution was measured using the perturbation method. The phase shift, which is approximately proportional to the square of the electric field, was measured by introducing a dielectric perturbing material. The end tuners and the fixed tuner positions were adjusted to minimize the field variations along the longitudinal position and quadrant-to-quadrant differences. Relative electric field distributions are shown in Fig. 2. Fields at the position of 2200 mm were about 7% higher than that at the entrance end, and quadrant-to-quadrant differences were less than 2.5%. These field variations and differences do not significantly affect the beam performance, which was estimated with the modified PARMTEQ simulation code.

The measured resonant frequency and Q-value of the accelerating mode were 201.2375 MHz and 9420, respectively. The frequency separation to the closest mode (TE_{111}) was 2.4 MHz. From the SUPERFISH result and the measured Q-value, it was predicted that an rf power of 363 kW was required to give the designed intervane voltage of 113 kV.

High-Power Conditioning

The tank had a conditioning so as to accept an rf high power. The rf power was coupled to the structure by an rf drive loop and a WX-203D coaxial line. The high-power rf was provided by an amplifier composed of a solid state amplifier and two-stages of power tubes (SIEMENS RS2058CJ and EIMAC 4CM2500KG)[3]. The vacuum pressure was kept

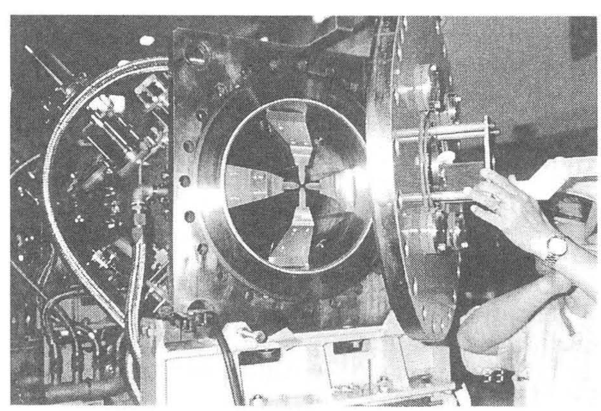

Fig. 1 View of the RFQ cavity

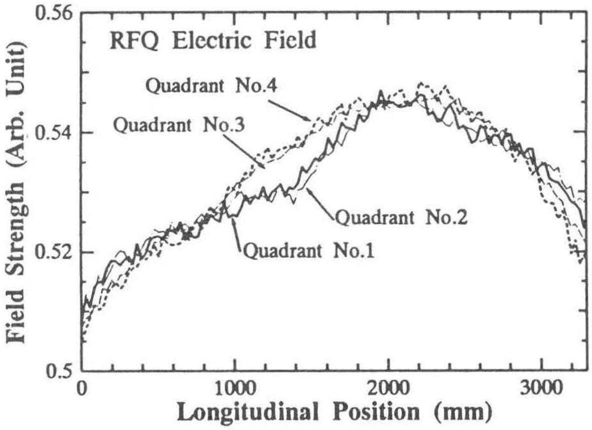

Fig. 2 Relative electric field strength along the position in the RFQ

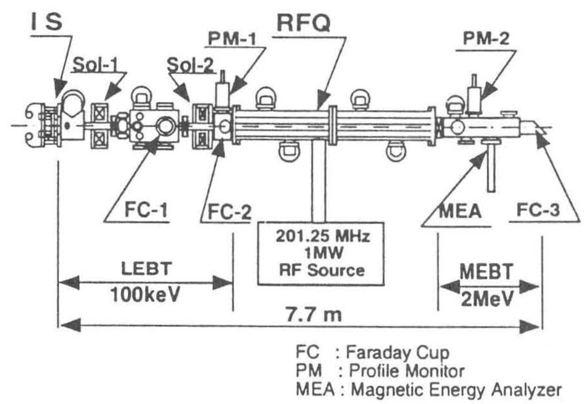

Fig. 3 Layout of the RFQ beam test

in the middle of 10^{-4} Pa (10^{-6} torr) range to avoid sparking with rf power in the tank, where it was 10^{-5} Pa without rf. The rf wave-forms from the directional coupler and the pickup loop were used as a monitor of the multipactoring and sparking. A TV camera was also used to observe sparks in the tank. A 3"ϕ x 3" NaI(Tl) detector or a HP-Ge detector was used to measure the cavity bremsstrahlung emission to determine the intervane voltage. The timing gate technique, the detector signal has a window during the rf period, greatly reduced the rf switching noise and the natural-backgrounds. This X-ray measurement confirmed that the rf power of 355 kW gave the designed vane voltage of 113 kV, which is consistent with the low-power tuning result.

After about one month of the conditioning, the tank accepted 363 kW, 280 kW and 260 kW rf power with duty factors of 0.6%, 6% and 12%, respectively. Although the rf conditioning did not achieve the designed duty factor, we expected the conditioning by the beam injection and concentrated on to the beam test.

First Beam Test

The first beam test was carried out at the test shop of Sumitomo Heavy Industries (SHI), Ltd. in Ehime-ken. The layout of the beam test is shown in Fig. 3. The input beam for the RFQ was provided by the multi-cusp type ion source, which was designed to 100 keV, 120 mA H^+[4]. Two focusing solenoids (Sol-1 and Sol-2) in the low energy beam transport (LEBT) matched the ion source beam emittance to the RFQ acceptance. A slit at the midpoint in the LEBT was used to control the input current and to reduce the molecular species contained in the beam. The diameters of the slit were 4, 10, 20 and 80 mm, and the typical RFQ input beam currents were 5, 25, 45, 90 mA, respectively.

Transmission was deduced from the RFQ input and output currents measured with the Faraday cups FC-2 and FC-3, respectively. Transmission as a function of the normalized vane voltage (a normalized vane voltage of unity corresponds to gap voltage of 113 kV) is shown in Fig. 4. This result is consistent with the PARMTEQ code predictions although measured transmission was lower by 20~30% for ϕ10 and ϕ20 mm slit and by 40~50% for ϕ80 mm slit, respectively. Two main reasons are considered for the overestimation of the RFQ input proton beam current by the Faraday cup (FC-2) in the LEBT;

1. We have a linear LEBT system without molecular species separation. The larger aperture slit is used, the lower proton fraction beam is expected.
2. The secondary electron suppression was assumed to be inadequate for the FC-2 because of the thin suppressor electrode due to the narrow space.

With the measurements of the proton fraction and accurate beam current, further measurements will be necessary to obtain the correct transmission through the RFQ,

Transmission as a function of the ion source acceleration voltage is shown in Fig. 5. There is a steep rise from 85 kV to 95 kV. This result is consistent with the PARMTEQ simulated result of the total (E>0 MeV) transmitted beam.

The beam energy spectra from the RFQ was measured using a compact magnetic energy analyzer (MEA), whose pole radius and gap length were 40 mm and 6 mm, respectively. The deflection angle was 25° and the energy resolution was assumed to be 5% for 2 MeV proton beam. The 100 keV H^+, H_2^+ and H_3^+ beam from the ion source through the RFQ (without rf) was used as an energy calibration source of the MEA. Figure 6 shows beam energy spectra for five vane voltages. As the vane voltage is reduced, the energy spectrum shifts to the lower energies.

Figure 7 shows a beam width (FWHM) as a function of the vane voltage at the position of the beam profile monitor (PM-2, 80 cm downstream from the RFQ). Since the profile monitor was a wire type, the beam pulse repetition was restricted to less than 2 Hz. The beam size in the Y-direction has a minimum point at the normalized vane voltage of 0.8. The results were in qualitatively agreement with the predicted results, which was simulated with the combination of the PARMTEQ and PARMILA codes.

In the first beam test, the acceleration current of 52 mA with a duty factor of 5% (repetition rate 50 Hz, pulse duration 1 msec) was achieved, although the testing period was restricted for one month due to the schedule of the test shop at SHI.

Summary

Low-power rf tuning and high-power rf conditioning verified the rf design features. The first beam test was successfully carried out in February 1994 and the peak acceleration current of 52 mA with a duty factor of 5% was achieved. Measured results were in general agreement with the PARMTEQ predictions, but further experiments will be required to obtain the more detailed characteristics.

After the first beam test, the RFQ was transferred from SHI to JAERI in April and reassembled. The connection to the high power amplifier has been completed and the re-conditioning is about to begin. The beam test in JAERI will be scheduled after October 1994, and operation at the designed current and duty factor will be anticipated.

References

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[2] K. Hasegawa et al.: "Design Study on an RFQ for the Basic Technology Accelerator in JAERI", ibid., p.314-316 (1992).

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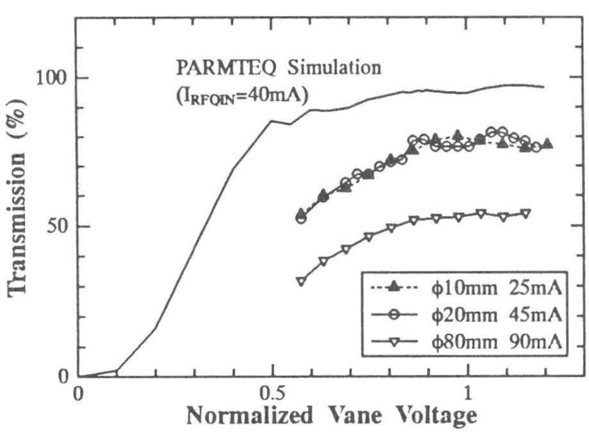

Fig.4 Transmission as a function of the vane voltage for three slit aperture sizes in the LEBT. Measured transmission rates were not corrected for the proton fraction in the RFQ input beam.

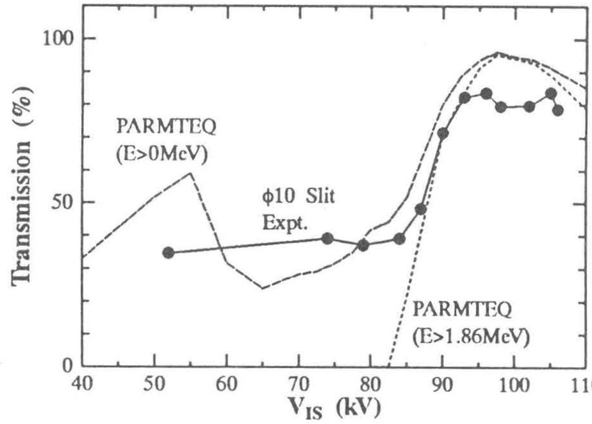

Fig. 5 Transmission as a function of the ion source acceleration voltage

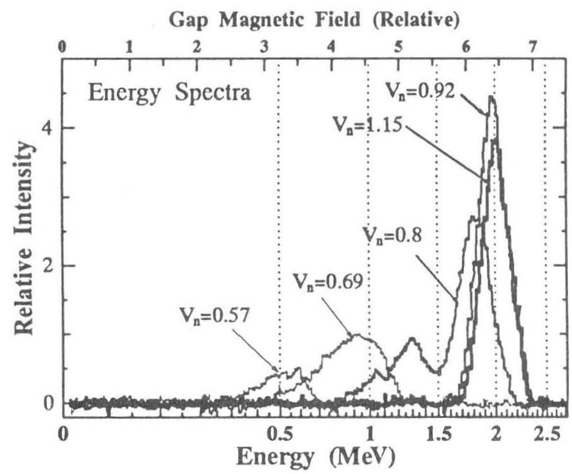

Fig. 6 Beam energy spectra for five normalized vane voltages

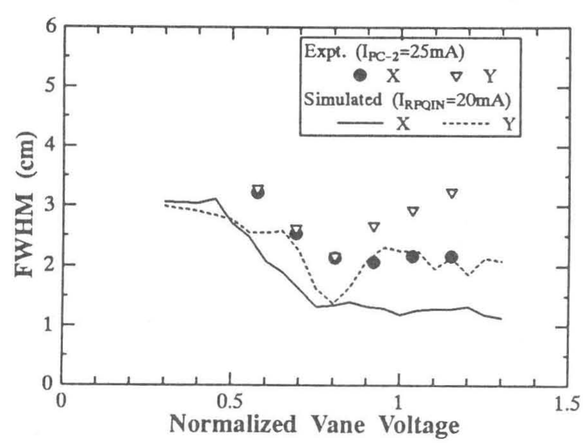

Fig. 7 Beam FWHM as a function of the vane voltage. Simulation was performed for I_{RFQIN}=20 mA, since a proton fraction of 80% was assumed in the FC-2 current.