Beam Tests of the "Modified" 34 MHz CW 4-rod RFQ

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Abstract

The development of the "modified" 4-rod RFQ linac system has been completed and a series of beam acceleration experiments has been done to check the performance of the machine. The linac was operated in cw mode and successfully accelerated several kinds of ion beams to their goal energies of 84 keV/u. The maximum beam currents obtained at the RFQ output were 32, 13, 220, and 330 pμA for He^+, N^{2+}, C^+, B^+ respectively with the beam transmission over 80 %.

Introduction

The features of the "modified" 4-rod RFQ are as follows:

1. an equally-spaced arrangement of the RFQ electrode supporting plates,
2. three dimensional machining of the RFQ electrode tips,
3. eccentrically-situated beam optics axis,
4. de mountable RFQ electrode assembly,
5. cw operation up to 50 kW.

Our design is to get a relatively small-diameter RFQ suitable for irradiation of light and medium ions with energies up to a few MeV. Table 1 summarizes the specifications of our linac system. Detailed descriptions of our linac design can be found in ref.[1]

Table 1
The specifications of the "modified" 4-rod RFQ linac system.

Injector:		
	Ion source	Freeman type
	Extraction voltage	50 keV max.
	Mass analyzer	90° magnet with sextupole corrections
	Focusing elements	four magnetic quadrupole lenses and one Einzel lens
	Beam optical length	2.5 m, including a beam monitor
	Size	1.5(W)×1.5(D)×1.8(H)
RFQ:		
	Type	fixed frequency "modified" 4-rod
	Frequency	33.3 MHz(design)
	Average bore radius	0.8 cm
	Focusing strength	6.79
	Inter-electrode voltage	54.9 kV
	Charge to mass ratio	1/11 (design)
	Injection energy	2.73 keV/u
	Output energy	83.5 keV/u (w/o half-cell)
	Length of electrode	222 cm (w/o half-cell)
	Cavity inner diameter	60 cm
	rf power	50 kW max.
	Operation mode	cw
	Transmission	≥80 %

Beam experiments have been in progress since the first successful beam test on December 25, 1992. The acceleration of He^+, N^{2+}, and C^+ ion beams were tested roughly in one year period at the ICR, Kyoto University, where the linac system was originally installed [1]. We obtained the beam currents of 32, 13, and 220 pμA for He^+, N^{2+}, and C^+, respectively with the beam transmission over 80 %. In December 1993, the whole linac system was moved to Kuze factory of Nissin Electric Co., Ltd. to continue with the acceleration tests of a B^+ ion beam. This is so done because the generation of this particular ions uses toxic gas and it needs a special exhaust system not available at ICR. The first beam at Kuze factory after the completion of re-assembling and coordination of the linac system was confirmed with a He^+ ion beam in late March. We then proved with He^+, N^{2+}, and B^+ ion beams that the performances of the linac were satisfactory or much better in reference to the data obtained at ICR. Meanwhile our beam emittance monitors were upgraded and installed in the linac system—older version lacked resolution in angle but this was corrected in the new ones. Summary of B^+ beam tests is presented in this report.

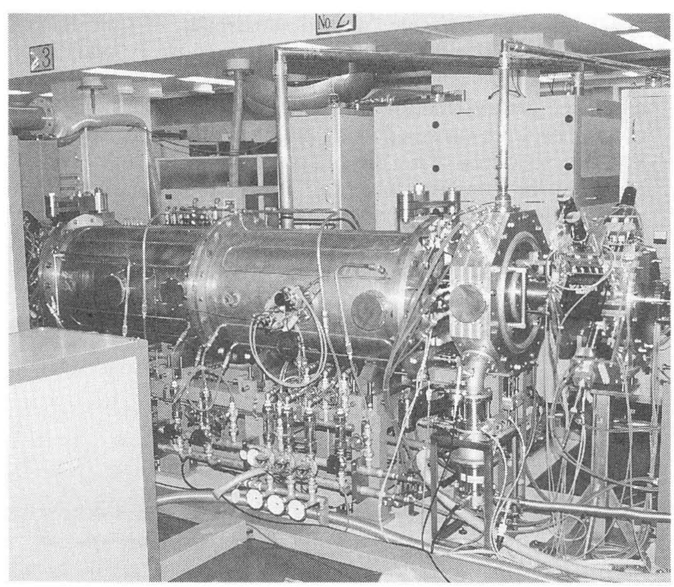

Photo. 1 Picture of the experimental setup at Nissin Kuze factory

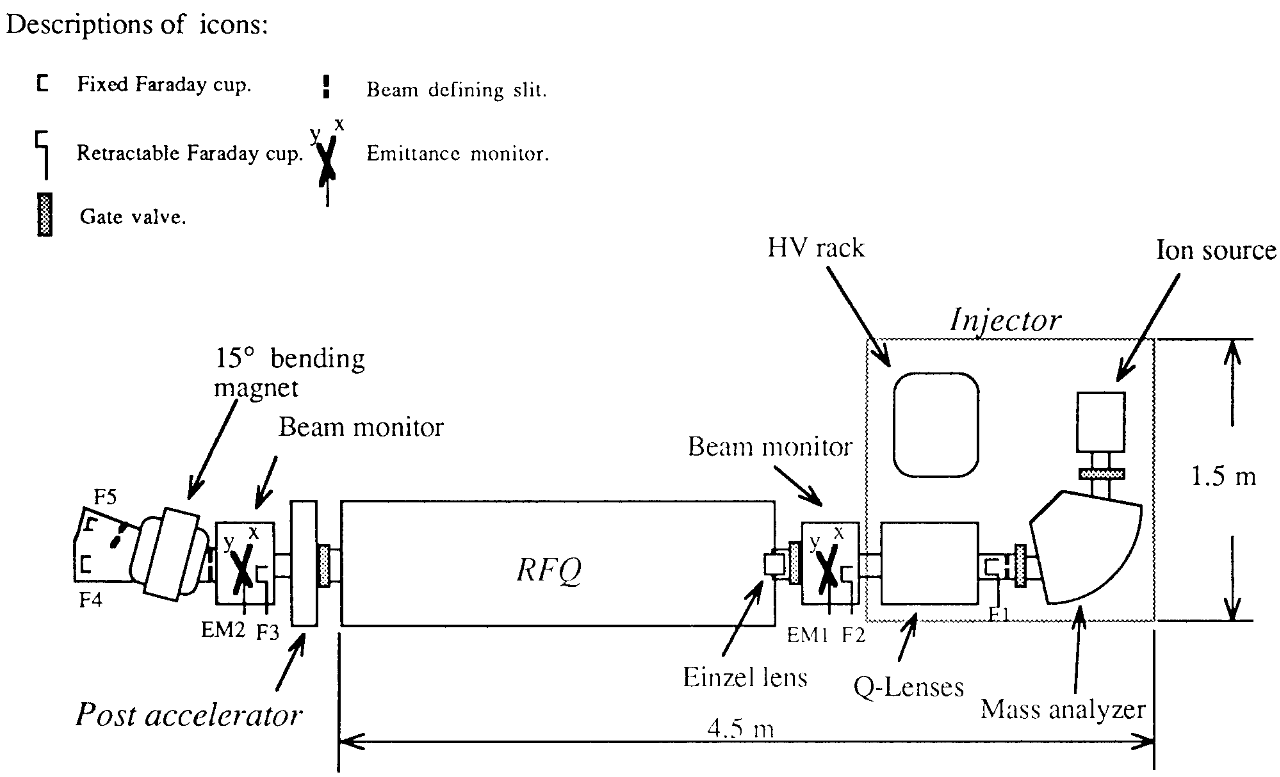

Fig. 1 Schematic drawing of the experimental setup of the RFQ linac system

Experiment

Setup

Photo. 1 is a picture of and fig. 1 is a schematic drawing of the experimental setup of the RFQ linac system. There are five Faraday cups in total to measure the intensity of an ion beam. F1 is retractable and practically works as a beam stopper as well as a beam electrode . F2 and F3 are retractable Faraday cups. F2 and F3 are used to measure the intensity of a beam at the upstream and downstream of the RFQ, respectively. F4 and F5 are both de-mountable Faraday cup systems and are similar to F2 and F3 in construction. The emittance and orientation in the trace-space of an input and output beam are surveyed using emittance monitors EM1 and EM2, respectively. They are of "two-slits" type, both exactly identical in construction [2]. Table 2 summarizes the specifications of the emittance gears and a schematic drawing of the system is shown in fig. 2.

Table 2
The specifications of the emittance monitors.

Slit width	0.5 mm (adjustable)
Thickness of the slits	1.0 mm
Drift distance between the slits	24 mm
Maximum range of the probe span	80 mm
(in reference to the beam optics axis)	±16 mm
Resolution of the probe position	0.01 mm
Maximum linear speed of the probe	0.5 mm/s

The energy of an input beam can be known accurately (better than ±0.5 %) by measuring a terminal voltage of the ion extraction high voltage power supply using an appropriate resistor divider. The output beam energy of the RFQ can be estimated by taking a momentum spectrum of a beam with the

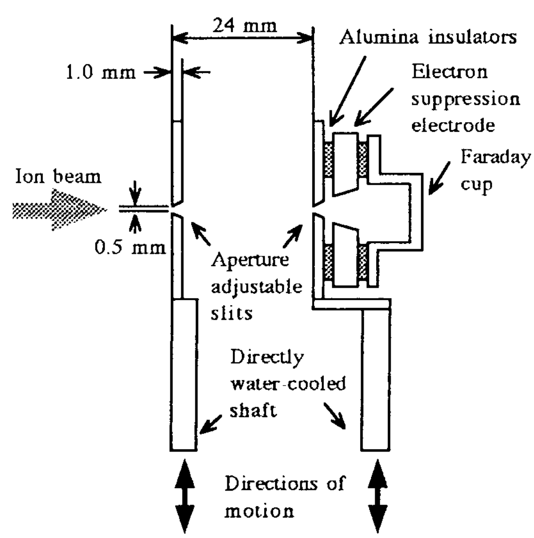

Fig.2 Schematic drawing of the emittance monitor

15° bending magnet system. Installed at the exit of our RFQ electrodes are half-cells of RFQ [3]. They are expected to suppress the divergence of an RFQ output beam—the effects of the half-cells are to be fully tested in the near future. Shown in fig. 1 but not explained in this report is the post accelerator of the RFQ. It is basically a $\lambda/4$ rf resonator that further accelerates or decelerates the output beam of the RFQ. The beam tests of the integrated system of the RFQ and $\lambda/4$ resonator have been in part completed at ICR, Kyoto University [4].

Data

Currents and transmissions The maximum current of a B^+ ion beam measured at F3 was 330 µA with the beam transmission of 80 %. Although the experimental setup is slightly different from the one at ICR, the results of current intensity measurements are summarized as in table 3 including previously measured data for He^+, N^{2+}, and C^+ ion beams:

Table 3 Typical results of beam intensity measurements.

Ions	Beam currents (pµA)	Beam transmission (%)
He^+	32	86
N^{2+}	13	79
C^+	220	78
B^+	330	80

Momentum spectrum Fig. 3 exemplifies a momentum spectrum of ion beams extracted from the ion source operated with BF_3 gas. The measurements were done by recording an ion current at F2 in varying mass analyzer's current. The extraction voltage was set at 30 kV the synchronous energy required for the RFQ injection.

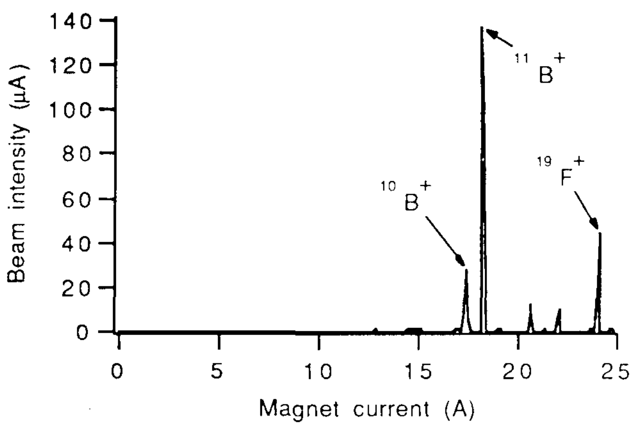

Fig. 3 Momentum spectrum of extracted ions from the ion source at energy of 30 keV.

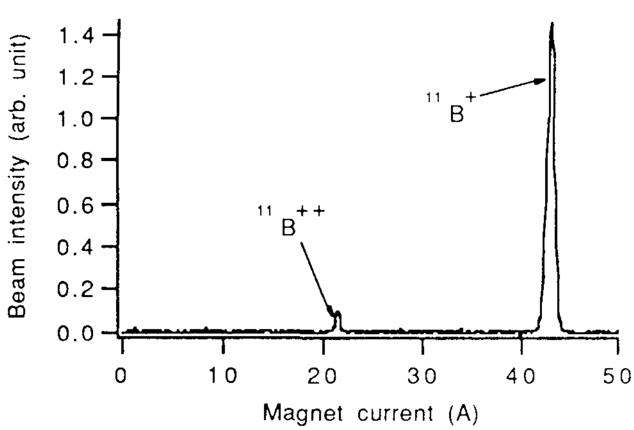

Fig. 4 Momentum spectrum of an accelerated B^+ beam.

The expected mass resolution M/ΔM of the 15° bending magnet is about 50. F5 measures the analyzed current of a beam which is collimated with the slits located both at the entrance and exit of the 15° magnet system. Fig. 4 typifies the momentum spectrum of an accelerated B^+ beam. The energy of the accelerated beam can be approximated by extrapolating from the spectrum of a mono-energetic beam from the ion source with the 15° bending magnet system. The estimated output energy of a B^+ beam is 987 KeV ± 6 %. This is off by + 6 % from the calculated output synchronous energy. A B^{++} peak appearing at the half value of the magnet current is identifiable as a charge-transferred B^+ beam: a small fraction of the B^+ beam from the RFQ collide with the residual gases and becomes B^{++} ions unchanged in their energies.

Emittance Fig. 5 typifies the results of beam emittance measurements for B^+ ion beams. The measurements were done at the probe position of 514 mm upstream of and 709 mm downstream of the RFQ electrode boundaries assuring 80 % beam transmissions. In the figure, the trace-space ellipses obtained by calculations using PARMTEQ and TRACE 3-D [5] are superposed on the raster images of the measured data. The un-normalized emittances represented by the ellipses are 62.7 πmm-mrad for the input in both x- and y-coordinates and 8.6 and 9.7 πmm-mrad for the output in x- and y-direction, respectively. Agreement is quite fair for the input but the other needs further study.

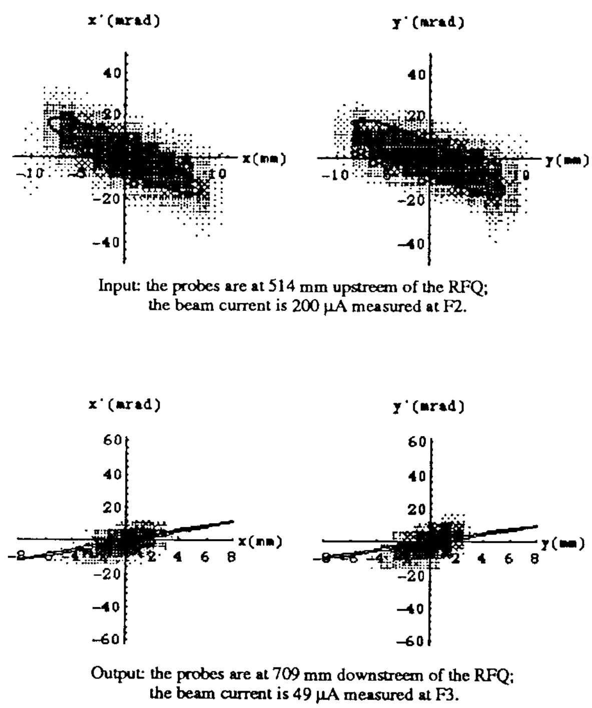

Fig.5 B^+ emittance data for the input and output of the RFQ

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