FIRST BEAM TESTS OF THE INS SPLIT COAXIAL RFQ FOR RADIOACTIVE NUCLEI

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Abstract

A 25.5-MHz split coaxial RFQ has come into operation at INS. This linac was designed so as to accelerate ions with a charge-to-mass ratio greater than 1/30 from 2 to 172 keV/u. The maximum intervane voltage so far achieved is 91 kV. We have conducted acceleration tests by using Ne$^+$ and N$^+$ ions. Through N$^+$ acceleration we obtained the following preliminary results. The output-beam emittances are well in the design ellipses of 0.06 π cm·mrad (normalized). The data of transmission efficiency vs intervane voltage agree well with PARMTEQ results. The transmission at the nominal voltage is measured to be 90%.

I. INTRODUCTION

The split coaxial RFQ presented here is to be used in a radioative-beam facility now under construction in INS [1]. Radioactive nuclei will be accelerated by the 25.5-MHz RFQ and a 51-MHz interdigital-H linac. The beam, whose energy is variable in a range from 172 to 1053 keV/u, is to be used for nuclear physics experiments.

The RFQ was designed so as to accelerate ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 up to 172 keV/u [2]. The cavity, comprising 12 module cavities, is 0.9 m in diameter and 8.6 m in length. It was set up in the experimental hall in the spring of 1994. We then made low-power tests for tuning of the resonant frequency and field distribution [3]. For the study of the acceleration performance we built a test stand, where a 2.4-GHz ECR ion source is located near the RFQ. In the middle of March, 1995, the cavity underwent aging for high-power operations. On March 22, we succeeded in the first acceleration by using a Ne$^+$ beam. Through further tests with a N$^+$ beam we found the beam performance agrees with PARMTEQ predictions. This paper describes the high-power operations and beam tests.

II. HIGH-POWER OPERATION

The rf power source with an EIMAC 4CW150,000E tetrode generates a maximum output power of 350 kW in peak with a duty factor of 30%. Higher duty factors, even 100%, are available at lower power levels. The rf power is transmitted into the cavity through a 6-m coax (WX-120D) and a loop coupler.

Figure 1 shows the progress in achieved intervane voltage ($V_{\rm vv}$) as a function of the aging time ($\equiv$ operation time $\times$ duty factor). The duty factor was changed as the rf power increased: 1% → 60% ($V_{\rm vv}$ = 0.2 $\rightarrow$ 0.56 kV), 80% (0.58 $\rightarrow$ 70 kV), and 10% (70 $\rightarrow$ 80 kV). The input power was increased gradually so that the cavity vacuum stayed in a range of $1 \sim 3 \times 10^{-6}$ Torr at a pump head[1] (0.5×10^{-6} Torr without power input). It took a long time to get over the multipactoring level lying between 15 and 20 kV. Through this aging the cavity came into stable operation at $V_{\rm vv}$ = 80 kV (20% duty, peak power = 130 kW). We then carried out the first acceleration with a Ne$^+$ beam.

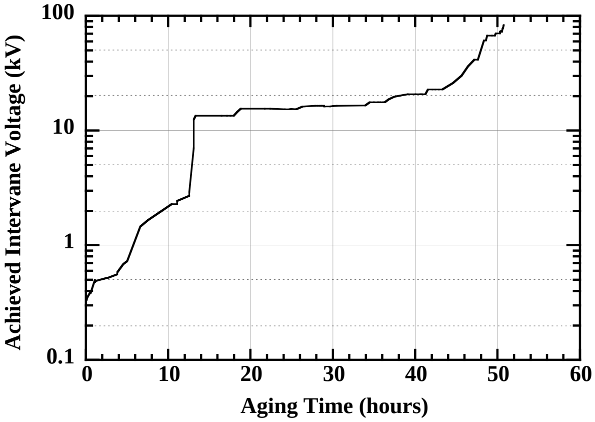

Figure 1. Achieved intervane voltage vs aging time ($\equiv$ operation time $\times$ duty factor).

We figure out intervane voltage from the output voltage ($V_{\rm ML}$) of a monitor loop attached to the 12th module cavity. The calibration constant $V_{\rm vv}/V_{\rm ML}$ is 10,388. For the calibration we measured endpoint energy of the X-ray from electrons accelerated between vane tips. A germanium detector cooled by liquid nitrogen, an amplifier, and a pulse height analyzer (PHA) were used. The factor for the conversion from a PHA channel into an energy is 0.10042 keV/ch. This value was obtained from two energy peaks from ^{57}Co: 122.6 keV (1219 ch) and 136.47 keV (1361 ch). The calibration constant $V_{\rm vv}/V_{\rm ML}$ was measured at five $V_{\rm vv}$ values between 44 and 77 kV. The averaged value and rms error of $V_{\rm vv}/V_{\rm ML}$ are 10,388 and 73.

In Fig. 2 the intervane voltage is plotted as a function of the input power ($P_{\rm in}$) to the cavity. In the figure $V_{\rm vv}^{\rm M}$ ($\circ$, $\bullet$) is the intervane voltage derived from the monitor loop voltage, and $V_{\rm vv}^{\rm X}$ ($\times$) from the X-ray endpoint energy. From the $V_{\rm vv}^{\rm M}$ values the resonant resistance $R_{\rm p}$ ($\equiv V_{\rm vv}^2/2P_{\rm in}$) is 24.55 $\pm$ 0.44 kΩ. This value is higher than 22 kΩ, which we obtained in low power tests [3]. The increase of the resonant resistance may be due to that the cavity Q-value might have increased through the aging.

Our goal is to operate the cavity at $V_{\rm vv}$ = 109 kV (design value for q/A = 1/30 ions, $P_{\rm in}$ = 240 kW) or higher with a duty factor of 30%. The cavity operates now stably at 80 kV ($P_{\rm in}$ = 130 kW, 20% duty). Reducing the duty factor down to 1.5%, we have achieved 91 kV ($P_{\rm in}$ = 170 kW). At this voltage we have now two problems: one is sparking between vane tips, and the other

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[1] Four 500-l/s turbomolecular pumps are evacuating the cavity.

is creeping discharge on the ceramic window (atmospheric side) of the loop coupler. These occur once per several minutes. After improving the loop coupler, we will conduct further aging for higher intervane voltages and duty factors.

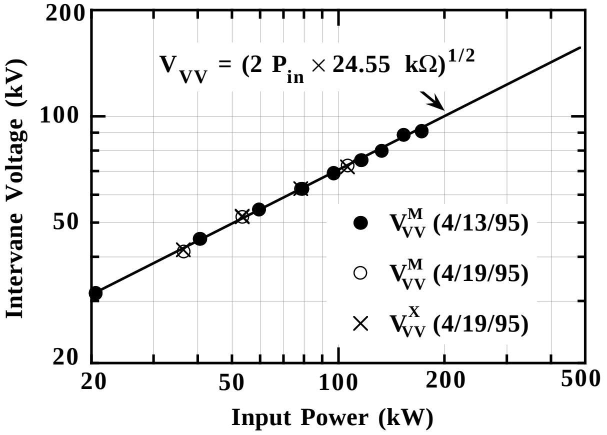

Figure 2. Intervane voltage vs input power into the cavity.

III. ACCELERATION TESTS

A. Test stand

Figure 3 shows the layout of the LEBT, which consists of a 2.4-GHz ECR ion source, a 90° bending magnet, two quadrupole magnets (defocusing in the horizontal plane), and four einzel lenses [4]. In front of the 3rd einzel lens, we set an electrostatic steerer, which has four electrode plates and deflects the beam in horizontal and viertical directions. At the entrance of the steerer we set a collimator (aperture radius is 0.65 cm) for ion separation. The collimator is effective in beam shaping also, cutting off beam filaments caused by the einzel lenses Nos. 1 and 2. A double-slit emittance monitor and a Faraday cup (FC1) are installed at the RFQ entrance.

The HEBT is illustrated in Fig. 4. The emittance monitor is separated into two parts: the front slit is near the RFQ exit, and the rear one is between the quadrupole magnets. The Faraday cup FC2 measures the current of drift-through ions (both of accelerated and unaccelerated ions), and FC3 the current of accelerated ions. The quadrupole doublet kicks out unaccelerated ions and focuses acceelerated ones into FC3. According to a beam simulation, less than 1% of unaccelerated ions reach FC3.

B. Beam performance

Figure 5 shows emittance porfiles at the RFQ entrance (vane end). The bars indicate measured profiles of a N^+ beam,[2] and the ellipses the designed ones with an area of 29.1 $\pi\ \mathrm{cm \cdot mrad}$ (ε_n = 0.06 $\pi\ \mathrm{cm \cdot mrad}$). The input match is imperfect: the beam center deviates by 0.19 cm in the horizontal (x) plane, and in the vertical phase space (y-y' space) the beam focusing is insufficient. The LEBT parameters deserve further tuning. Figure 6 shows emittance porfiles at the RFQ exit (vane end). The RFQ operated at the nominal intervane voltage, 50.68 kV for N^+. The measured profiles are inside of the ellipses, whose area is 3.11 $\pi\ \mathrm{cm \cdot mrad}$ (ε_n = 0.06 $\pi\ \mathrm{cm \cdot mrad}$) and the Twiss parameters are expected ones from a PARMTEQ simulation.

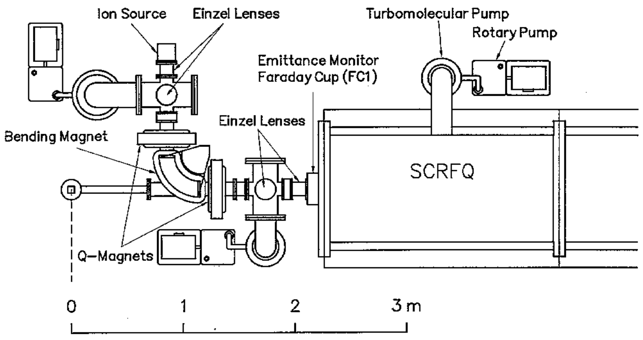

Figure 3. Layout of the LEBT

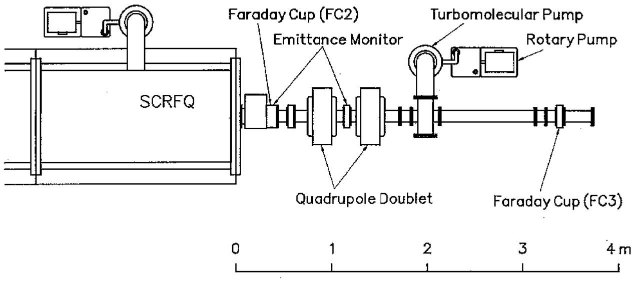

Figure 4. Layout of the HEBT

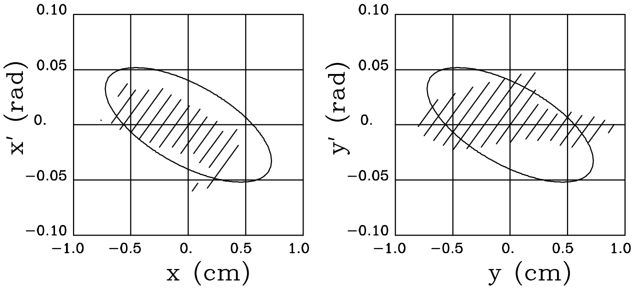

Figure 5. Emittance profiles at the RFQ entrance.

We measured the transmission efficiency as a function of the intervane voltage. The RFQ operated at 25.47 MHz with a duty factor of 5% (0.53 ms × 95 Hz), and the ion source synchronized the RFQ. The N^+ beam had the input emittance profiles shown in Fig. 5, and the current was 0.21 ∼ 0.22 mA in peak at FC1. The measurement result is shown in Fig. 7 along with a PARMTEQ prediction. The horizontal scale is the normalized intervane voltage, $V_n = V_{VV}$/50.68 kV. The measured transmission efficiency of drift-through ions (○ in the figure) is defined by I(FC2)/I(FC1), where I(FCi) is the beam current from the Faraday cup i, and that of accelerated ions (●) by I(FC3)/I(FC1). The PARMTEQ simulation was done by using the PARMTEQ-H version, where the electric field has the higher-order mulitipoles calculated by Crandall [2, 5]. The input emittance profiles are ellipses approx-

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[2] Some of the ions may be N_2^{2+}; we cannot discriminate between N^+ and N_2^{2+} ions in our test stand.

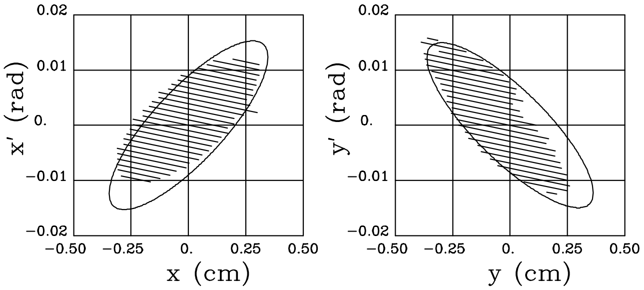

Figure 6. Emittance profiles at the RFQ exit.

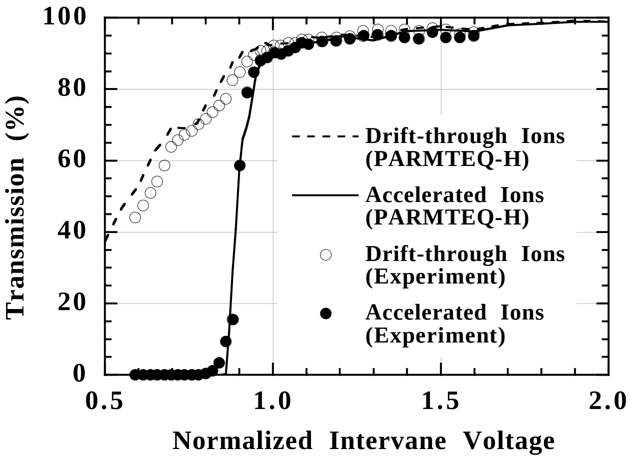

Figure 7. Transmissions vs normalized intervane voltage.

imately same as the measured ones in Fig. 5. Some of the unaccelerated ions have so large divergences that they might miss FC2 (aperture radius = 1.7 cm). The missing rate is 10% or less. This was taken into account in the simulation.

At the nominal intervane voltage (V_{n} = 1) the measured transmission efficiency is 90%. This is close to the design value of 91.4% with a matched input beam with ε_{n} = 0.06 π $\mathrm{cm} \cdot \mathrm{mrad}$. Though the input match is rather poor in the y-y' space (Fig. 5), we obtained a high transmission. This is due to the RFQ acceptance larger than 0.06 π $\mathrm{cm} \cdot \mathrm{mrad}$ normalized. Running PARMTEQ-H, we get a transmission of 90% for a matched beam with ε_{n} = 0.09 π $\mathrm{cm} \cdot \mathrm{mrad}$ [2].

IV. CONCLUDING REMARKS

The measured output beam emittances and transmission efficiencies show that the performance of the RFQ is close to the designed one. The input power is, however, still low. The maximum averaged power in the above measurement was 6.7 kW (134 kW × 0.05) at V_{vv} = 81 kV (V_{n} = 1.6 in Fig.7). We are aiming at the operation at V_{vv} = 109 kV with a 30% duty; then the averaged power will be 73 kW (242 kW × 0.3). Under this high-power, high-duty operation, the frequency stabilization is indispensable. For the frequency control, we have already installed eight inductive tuners with stepping motors to the cavity. Our experience with the prototype RFQ tells us that the tuners will keep the frequency under control [6]. Another possible problem with a heated cavity is distortion of the vanes; the beam performance may be affected. From this anxiety we chose a water-pipe diameter larger than that at the prototype RFQ. At the full power operation of the present RFQ, the averaged power loss per cavity length will be 8.5 kW/m (73 kW/8.6 m). At the prototype RFQ we had increased the power up to 7.6 kW/m (16 kW/2.1 m) and observed no appreciable change in the beam performance. From this experience and the increased flow rate of the cooling water, we expect the RFQ will work well under the full power operation.

V. ACKNOWLEDGMENTS

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