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

Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan

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 τ 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 radioactive-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 cavity vacuum stayed in a range of 1 ~ 3 × 10⁻⁶ Torr at a pump head¹ (0.5 × 10⁻⁵ 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 V₁ = 80 kV (20% duty, peak power = 130 kW). We then carried out the first acceleration with a Ne⁺ beam.

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

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 (V₁) as a function of the aging time (≡ operation time × duty factor). The duty factor was changed as the rf power increased: 1% → 60% (V₁ = 0.2 → 0.56 kV), 80% (0.58 → 70 kV), and 10% (70 → 80 kV). The input power was increased gradually so that the cavity vacuum stayed in a range of 1 ~ 3 × 10⁻⁶ Torr at a pump head¹ (0.5 × 10⁻⁵ Torr without power input). We figured out intervane voltage from the output voltage (V₅) of a monitor loop attached to the 12th module cavity. The calibration constant for transmission efficiency vs intervane voltage, and intervane voltage derived from the monitor loop voltage, and V₅ (×) from the X-ray endpoint energy. From the V₅ values the resonant resistance Rₚ (≡ V₅² / 2Pₚ) is 24.55 ± 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 V₁ = 109 kV (design value for q/A = 1/30 ions, Pₚ = 240 kW) or higher with a duty factor of 30%. The cavity operates now stably at 80 kV (Pₚ = 130 kW, 20% duty). Reducing the duty factor down to 1.5%, we have achieved 91 kV (Pₚ = 170 kW). At this voltage we have now two problems: one is sparking between vane tips, and the other
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.

### 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 vertical 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 fragments 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 accelerated ones into FC3. According to a beam simulation, less than 1% of unaccelerated ions reach FC3.

#### B. Beam performance

Figure 5 shows emittance profiles at the RFQ entrance (vane end). The bars indicate measured profiles of a N⁺ beam, and the ellipses the designed ones with an area of 29.1 cm mrad (εₓ = 0.06 π cm 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 profiles 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 π cm mrad (εₓ = 0.06 π cm mrad) and the Twiss parameters are expected ones from a PARMTEQ simulation.

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, $V_{vv} = V_{vv}/50.68$ kV. The measured transmission efficiency of drift-through ions (○ in the figure) is denoted by (FC2)/(FC1), where $l_i$ (FCi) is the beam current from the Faraday cup i, and that of accelerated ions (●) by $l_i$ (FC3)/(FC1). The PARMTEQ simulation was done by using the PARMTEQ-H version, where the electric field has the higher-order multipoles calculated by Crandall [2, 5]. The input emittance profiles are ellipses approx-

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2 Some of the ions may be N₂⁺; we cannot discriminate between N⁺ and N₂⁺ ions in our test stand.
Figure 6. Emittance profiles at the RFQ exit.

Figure 7. Transmissions vs normalized intervane voltage.

approximately 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 $\varepsilon_n = 0.06 \, \pi \, \text{cm} \cdot \text{mrad}$. 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 $\pi$ cm $\cdot$ mrad normalized. Running PARMTEQ-H, we get a transmission of 90% for a matched beam with $\varepsilon_n = 0.09 \, \pi \, \text{cm} \cdot \text{mrad}$ [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 $\times$ 0.05) at $V_{nV} = 81$ kV ($V_n = 1.6$ in Fig. 7). We are aiming at the operation at $V_{nV} = 109$ kV with a 30% duty; then the averaged power will be 73 kW (242 kW $\times$ 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.

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References


