RF TESTS ON THE INS 25.5-MHZ SPLIT COAXIAL RFQ

S. Shibuya*, S. Arai, A. Imanishi, T. Morimoto, E. Tojyo, and N. Tokuda

Institute for Nuclear Study, University of Tokyo
Tanashi, Tokyo 188, Japan

Abstract

A 25.5-MHz split coaxial RFQ with modulated vanes has been constructed. This RFQ will accelerate heavy ions with a charge-to-mass ratio greater than 1/30. We have finished field measurements and obtained the following results: the field strengths between neighboring vanes are same within ±0.6% over the vane length; the distribution of the intervane voltage in the axial direction is almost flat. Through high power tests so far conducted, we have attained an intervane voltage of 110 kV under a pulse operation with a peak power of 70 kW and a duty factor of 0.9%. The cavity is thus almost ready for acceleration tests.

Introduction

We have constructed a 25.5-MHz split coaxial RFQ with modulated vanes, and will accelerate heavy ions with a charge-to-mass ratio (q/A) greater than 1/30. The whole cavity consists of three module cavities. The cavity structure and its design procedure were reported elsewhere,[1,2] and main parameters of the RFQ are summarized in Table I. The RFQ presented here is a prototype of a real machine for the Japanese Hadron Project. The operating frequency and the length of a real machine under design are respectively 25.5 MHz and 22 m. This real machine will accelerate unstable nuclei ($q/A \geq 1/60$) up to 170 keV/u.[1]

Soon after the completion of the cavity construction in October, 1989, the resonant frequency was roughly tuned to 25.45 MHz.[2] Further fine tuning to 25.5 MHz was afterward accomplished by using three inductive tuners: a cylindrical aluminum block (188 mm in diameter) was inserted into each module cavity. We obtained experimentally the relation between the tuner length and the resonant frequency, and determined finally the length so that one tuner increases the frequency by 17 kHz. The distance between the beam axis and the tuner end is now 170 mm. The resulting resonant frequency is 25.5 MHz, and the unloaded Q-value is 6400. Through field measurements we obtained satisfactory results, as will be discussed below.

We are now conducting high-power tests by using a power supply with the following specifications: 100 kW in the maximum peak power, 10% in the maximum duty factor, 50 μs ~ 3 ms in pulse width. The rf power is fed into the cavity through a coaxial wave guide (WX-120D) and a loop coupler cooled with water. We have so far attained a intervane voltage of 110 kV under a pulse operation with a peak power of 70 kW and a duty factor of 0.9%.

This paper describes measurements of field distributions along the vanes and presents preliminary results of high-power tests.

*The Graduate University for Advanced Studies, KEK, Tsukuba, Ibaraki 305, Japan

TABLE I

Main Parameters of the Prototype RFQ

Frequency (f)	25.5 MHz
Charge-to-mass ratio (q/A)	$\geq 1/30$
Input energy (T_{in})	1 keV/u
Output energy (T_{out})	45.4 keV/u
Normalized emittance (ε_n)	0.6 π mm·mrad
Vane length (L)	2.135 m
Kilpatrick factor (f_K)	2.2
Intervane voltage (V_v)	109.3 kV*
Mean bore radius (r_0)	0.946 cm
Minimum bore radius (a_{min})	0.521 cm
Margin of bore radius (a_{min}/a_{beam})	1.20
Focusing strength (B)	6.0
Limiting current (I_{lim})	2.5 mA*

* for $q/A = 1/30$ ions.

Field Measurements

We measured distributions of electric field strengths in the cavity by means of a perturbation method. When a perturbator comes into a cavity, the resonant frequency (f_0) changes (by Δf). Furthermore, the difference between the phase of the input wave and that of the transmitting wave shifts (by θ). These are expressed as:

$$-\tan\theta \simeq 2Q_0 \frac{\Delta f}{f_0} \propto E^2 , \qquad (1)$$

where Q_0 is the unloaded Q-value, and E the electric field strength at the perturbator position. We measured the above θ for the evaluation of field strengths.

We examined the filed balance among the quadrants by measuring field strengths between vanes. A teflon perturbator (20 mm in diameter and 10 mm in length) was set between vanes, as shown in Fig. 1, and moved in the axial direction (the perturbator always touched two vanes). The measured θ's are shown in Fig. 1, where four curves, corresponding to the four perturbator positions between vanes, are drawn. At any axial position, each of four field strengths deviates from their average value by less than ±0.6%.

Field strengths in the beam aperture were measured with a teflon perturbator, 9.5 mm in diameter and 7.5 mm in length. The thick line in Fig. 2 is the result. The observed oscillation is due to the modulation of the vanes, as can be explained by a numerical calculation. From Eq. (1), we see that the phase shift θ is related to the energy of the electric field in the perturbator region. The field energy was computed by using electric field components derived from the Kapchinskij-Teplyakov potential function[3] and design values of vane parameters at each cell. The intervane voltage was assumed to be constant over the vane length, as is in the design. For comparison with the above

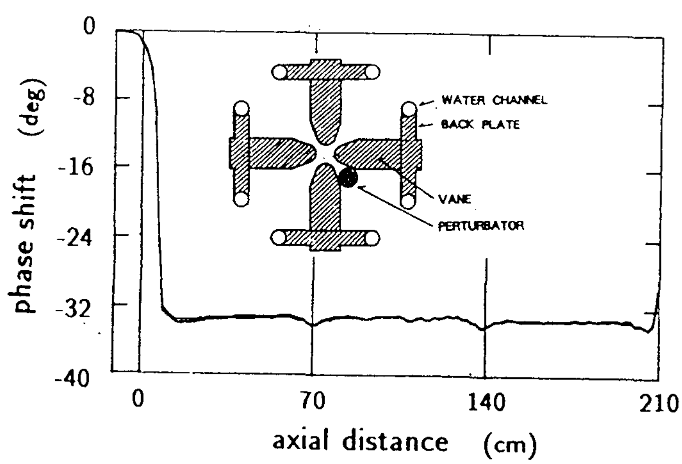

Fig. 1. Measured field strengths between neighboring vanes (four curves are drawn) and the perturbator position.

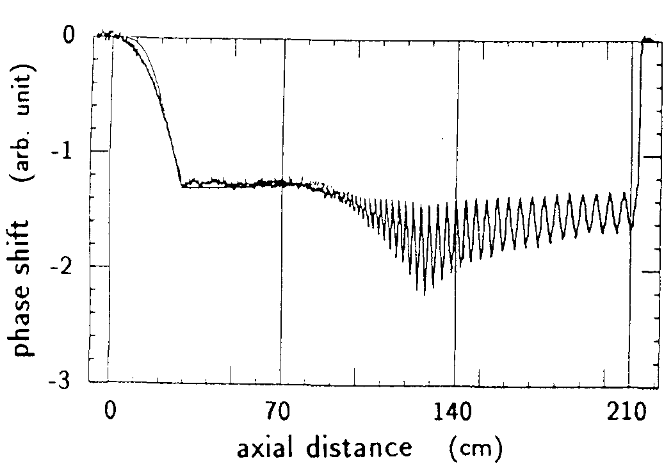

Fig. 2. Measured (thick line) and computed (thin line) electric field strengths in the beam aperture.

experimental data, the computed values of θ were normalized so that the measured and the computed θ's are equal at the exit of the radial matching section, 30 cm down from the cavity entrance. The thin line in Fig. 2 is the result of the computation. From the good agreement between the two curves, we infer that the intervane voltage is almost flat over the vane length, and that the electric field in the beam aperture is close to the ideal one.

High Power Tests

Measurements of intervane voltage

During high-power operations we should be able to measure intervane voltage. Two measurement techniques have been tried, and they yielded results consistent to each other.

One of the techniques is to measure a voltage of a signal from a monitor loop attached to the cavity side wall. The size of the loop and its angle to the magnetic flux were adjusted so that the picked-up signal might have a voltage about 1/10000 of the intervane voltage. For the calibration, we applied directly voltage between two neighboring vanes by connecting them to a signal generator with a cable and measured the output voltage of the monitor loop.[4] The resulting monitor-loop voltage against an intervane voltage of 1V was 0.1225 mV.

The other technique is to measure an input power P_{in} supplied to the cavity and calculate an intervane voltage V_v from the following relation:

$$V_v = \sqrt{2 R_p P_{in}} \,, \tag{2}$$

where R_p is the resonant resistance of the cavity. The value of R_p was experimentally obtained. We applied a certain voltage V_v to vanes in the manner same as at the calibration of the monitor loop, and measured a voltage V_c across a 50-Ω resistor terminating the loop coupler for high-power rf feed. We found thereby

$$R_p = 50 \left(\frac{V_v}{V_c} \right)^2 \tag{3}$$

$$= 86.8 \text{ k}\Omega \,.$$

The resonant resistance can be derived from another relation. Using measured values of the unloaded Q-value (Q_0 = 6400), the resonant frequency (f_0 = 25.5 MHz), and the capacitance (C = 453 pF) of the inner electrode, we obtained

$$R_p = \frac{Q_0}{2\,\pi\, f_0\, C} \,, \tag{4}$$

$$= 88.2 \text{ k}\Omega \,.$$

Substituting these R_p-values into Eq. (2), we obtained intervane voltages as functions of input power; the two curves in Fig. 3 are the results.

In the figure the curves are compared with open circles. The circles were plotted by using input powers indicated on a meter of the power supply and intervane voltages obtained from monitor-loop outputs. The three

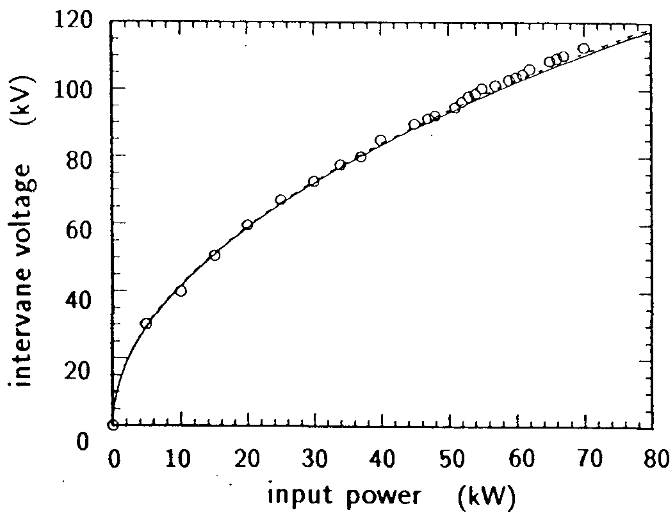

Fig. 3. Relation between intervane voltage and input power. The solid line is derived from Eq. (2) with $R_p = 86.8$ kΩ, and the dashed line with $R_p = 88.2$ kΩ. The open circles denote intervane voltages derived from monitor-loop signals as functions of the input power measured with a power meter.

results *i.e.*, the two curves and the set of open circles, are same within ±1.1%.

Cavity conditioning for high-power operations

We have attained an intervane voltage of 110 kV under a pulse operation with a duty factor of 0.9% and a peak power of 70 kW. This voltage is high enough to accelerate ions with a charge-to-mass ratio of 1/30; 109 kV is necessary for the ions. The high intervane voltage was attained after a conditioning, where we trained the cavity under operations with duty factors of 3% ~ 0.6% and increased the input power step by step so that the vacuum in the cavity might be kept less than 7×10^{-6} Torr.

Figure 4 shows the progress in attained intervane voltage during the conditioning. At the beginning we increased gradually the input power at lower levels, but could not stabilize the operation. After such a state lasting, the intervane voltage jumped abruptly to 6 kV, and the cavity came into a stable operation at this level. As the input power was increased further, the shape of the signal from the monitor loop warped and the vacuum got worth rapidly. These phenomena, caused by multipactoring, were observed at certain ranges of the intervane voltage. The multipactoring was severer at lower voltages, as indicated by the three plateaus in Fig. 4. From the observed multipactoring levels, we found that the applicable intervane voltages are at present between 6 kV and 110 kV, and that the RFQ can accelerate ions with a charge-to-mass ratio between 1/2 and 1/30.

Concluding Remarks

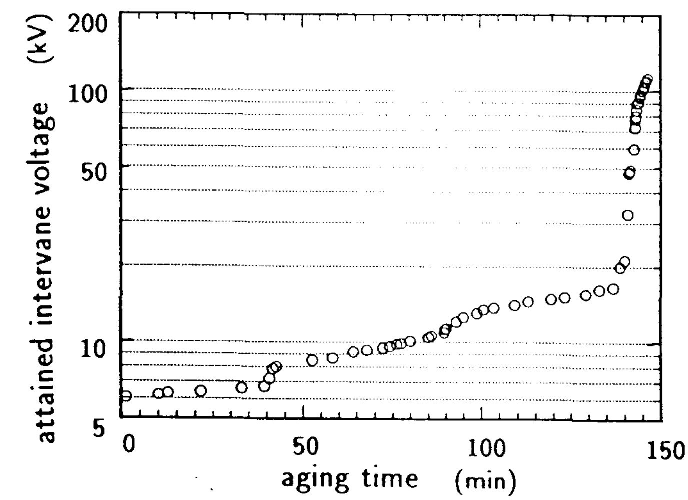

Fig. 4. Attained intervane voltage as a function of aging time, *i.e.*, operation time × duty factor.

The field measurements have verified that a good electric field is generated in the beam aperture. From our experience with other RFQ's at INS, we consider that the obtained field balance among the quadrants and the flat voltage distribution in the axial direction promise well for acceleration tests to be conducted soon. The issues of high-power tests from now on are 1) increase of the duty factor up to 10%, 2) examination of temperature increase and frequency shift under high-duty operations, and 3) measurement of the voltage break-down level. After constructing a test stand, we will accelerate N_2^+ ions.

Acknowledgments

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