The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

PERFORMANCE OF THE INS SPLIT COAXIAL RFQ

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Abstract

A proton accelerating model of a split coaxial RFQ with modulated vanes is constructed. The split coaxial RFQ is developed for the acceleration of very heavy ions like uranium. This model is a 1/4 scale of the real machine, and the operating frequency is 50 MHz. By employing a multi-module cavity structure, the four vanes are installed with a good accuracy in the split coaxial resonator and the required azimuthal field valance is achieved. A beam acceleration test shows that a proton beam is accelerated from 2 to 60 keV, as was designed.

Introduction

In the proton or heavy-ion linear accelerator system, RFQ is very suitable to a preinjector used instead of the large scale Cockcroft-Walton between the ion source and the conventional drift-tube linac, because the RFQ can accelerate low-β particles with good transmission efficiency. Especially for the very heavy ion acceleration, the feature of RFQ is made use sufficiently. However, a rational resonant structure is required to keep the volume of the cavity as small as possible and to get the stable accelerating field, because the operating frequency of the RFQ for accelerating the very heavy ions becomes low such as 10 ~ 15 MHz.

A multi-module split coaxial RFQ with modulated vanes has been developed at Institute for Nuclear Study (INS)[1-4] based on an idea of the split coaxial resonator invented by Müller[5,6] and on the experience with a four-vane type RFQ[7]. So far, the mechanical and rf characteristics of this RFQ structure were investigated experimentally by means of a cold model with flat vanes, which is excited in a frequency range of 37 ~ 41 MHz. The experimental results showed that the precise vane alignment, good mechanical stability and the required field distribution were obtained by employing the multi-module cavity structure. Furthermore, by analyzing this structure theoretically, the longitudinal field distribution in the fundamental and higher harmonics modes and the dispersion characteristics of the resonator were well explained and the design method of the structure was improved[8].

A proton accelerating model working at frequency of 50 MHz was constructed to evaluate the overall performance of the multi-module split coaxial RFQ. This model consists of four-module cavities which is about 2 m in total length and 0.4 m in diameter. In the beam test, it was confirmed that the proton beam was accelerated from 2 to 60 keV at the designed vane voltage of 2.9 kV.

Outline of the Accelerating Model

A structure of the multi-module split coaxial RFQ is shown in Fig.1 schematically. The features of the structure are as follows: the cavity diameter is small even for low operating frequency; the resonant mode is stable; the intervane voltages in all quadrants are originally equal; and the required voltage flatness along the beam axis is obtained inherently. Furthermore, the vane voltage distribution is insensible to the change of the dimensions in each module, since each module is strongly coupled on rf with each other. Azimuthal field balance is determined only by the distance of vane-gap. In the case of our RFQ having a mean bore radius of 0.54 cm, the vanes were aligned with accuracy better than ±0.1 mm, in order to keep the error of the field balance less than ±2.5 %.

Main vane parameters are summarized in Table 1. The vanes were designed by laying emphasis on high acceleration rate rather than high beam current. The injection energy was set at a relatively low value of 2 keV.

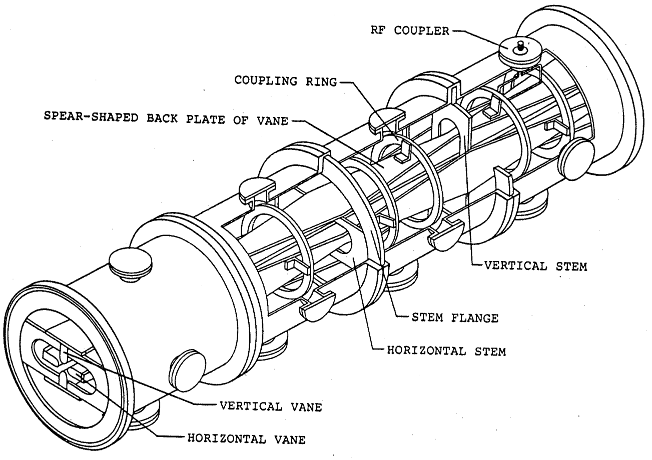

Fig.1. Structure of the four-module split coaxial RFQ.

Table 1. Design parameters of the vane.

	Design	
Frequency (f)	50	MHz
Kinetic energy (T)	2.00 → 59.6	keV
Normalized emittance (ε_N)	0.03	π cm·mrad
Intervane voltage (V)	2.9	kV
Focusing strength (B)	3.8	
Max. defocusing strength (Δ_b)	-0.075	
Synchronous phase (ϕ_s)	-90 → -30	deg
Max. modulation (m_{max})	2.48	
Number of cells	168	
Vane length	205.19	cm
Mean bore radius (r_0)	0.541	cm
Min. bore radius (a_{min})	0.294	cm
Margin of bore radius (a_{min}/a_{beam})	1.15	
Transmission (0 emA)	84	%
(2 emA)	69	%
(4 emA)	56	%

The tanks were made of brass. The modulated vanes and the stems supporting them, were made of aluminum alloy. Each vane of 205 cm long was completed by connecting 11 short vane pieces of 20 cm long. The rf power is fed into the first tank through a loop coupler. The rf level in each module is monitored by using pickup loops installed at the center in each module tank.

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Radio Frequency Aspects

Tuning of the Structure

Resonant frequency is determined by the intervane capacitance, the tank inductance and the stem inductance. Rough tuning of the structure was performed by adjusting the stem inductance. The inductance due to the stems is affected remarkably by the open area which is surrounded by the stems and the stem flange. The stem inductance decreases when the open area becomes smaller, and is vanished in the extreme case when the structure of the module end is the wall instead of the stems. In the case of four-module cavity structure, the module ends having such area are three. The change of the resonant frequency was measured every time when the module ends were closed by the wall plates. The result is shown in Fig.2. Based on the experimental result, all module ends were closed in order to bring the resonant frequency close to 50 MHz.

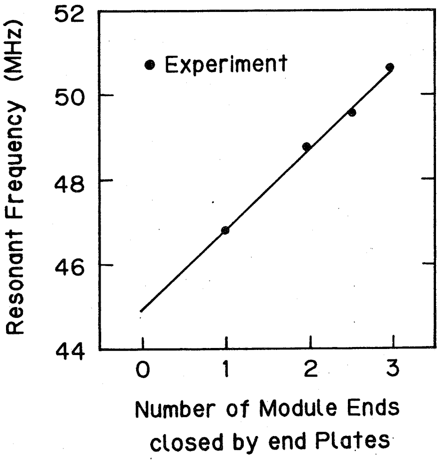

Fig.2. The change of the resonant frequency when the module ends are closed.

Field Distributions

Azimuthal field distribution was examined by a measurement of the longitudinal field distributions in the quadrants. The longitudinal field distributions were measured with a perturbation method.

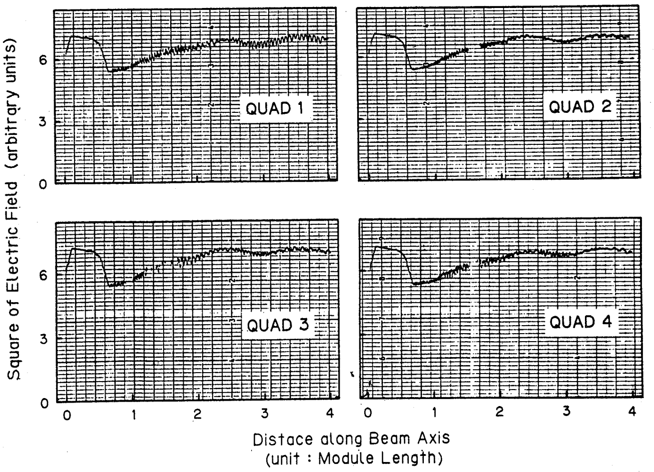

Fig.3. Azimuthal field distribution

A dielectric perturbator, 10 mm in length and 10 mm in diameter, was moved with a pulse motor, using the vanes as a guide. The result is shown in Fig.3: the azimuthal field unbalance is less than ±1%. The longitudinal field distribution in the radial matching section was measured by passing a dielectric rod, 10 mm in diameter and 8 mm in length, through the beam aperture. The result is shown in Fig.4.

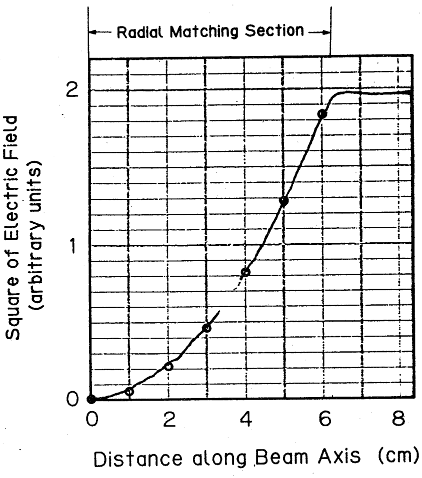

Fig.4. Longitudinal field distribution in the radial matching section. Circles show a calculation.

In the radial matching section, longitudinal electric field is constant along the beam axis, and transverse electric field increases linearly along the beam axis. A calculation in which the shape of the perturbator is considered agrees well with the experimental result.

Rf Conditioning

The design rf voltage of 2.9 kV was reached after conditioning to exceed the multi-pactoring level. The rf conditioning was done with a cw power of about 75 watts for 4 hours under a vacuum of about 1×10^{-5} Torr. The conditioning improved the unloaded Q-value from 1860 to 2230. This value corresponds to a resonant resistance of 18.3 kΩ.

Beam Acceleration Test

A beam acceleration test was performed under the pulse operation with a duty factor of 8%. The pulse width of rf voltage and the pulse length of the output beam are 200 μs and 100 μs, respectively, as shown in Fig.5.

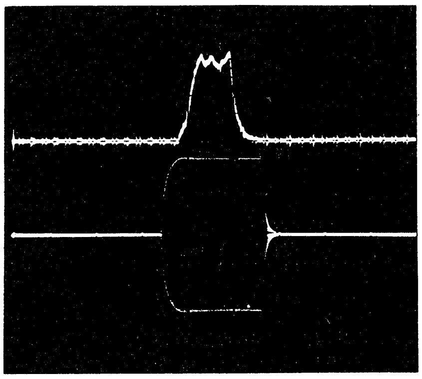

Fig.5. Pulse wave forms of the beam (top) and the rf voltage (bottom).

The layout of a test stand is shown in Fig.6. Proton beam is produced by a compact ion source of ECR type. The beam, which passed through an ion separating magnet, is matched to the RFQ acceptance by means of three sets of einzel lenses and a electric quadrupole triplet. Energy of the output beam is measured by a magnetic spectrometer system. The energy resolution of the system is ±0.7 %. The beam current is measured by Faraday cups.

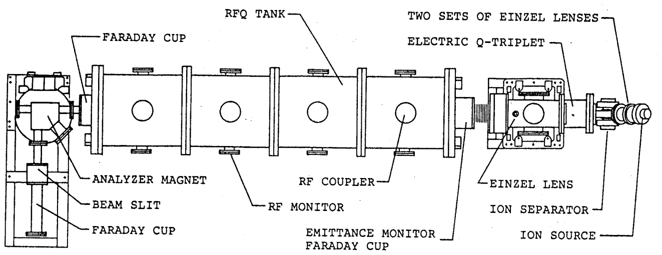

Fig.6. Layout of a test stand.

Transmission

Transmission was measured as a function of rf voltage. The result is shown in Fig.7. Two transmission curves (dotted and solid lines) express the beam currents measured by two Faraday cups following the RFQ and located downstream of the analyzer magnet, respectively. The results show that the nonaccelerated beam is transmitted at the lower voltage than the designed voltage. The difference between two transmitted currents at the design voltage is considered to be due to a limited acceptance in the analyzing system.

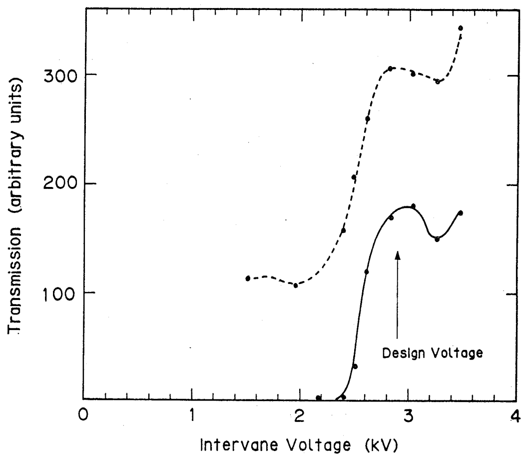

Fig.7. Transmission measured as a function of the rf voltage.

The ratio of the output beam current to the input one was about 60 %. However, the exact transmission efficiency is unknown at the present time, because the input beam emittance has not been measured yet.

Energy Spectrum

Output beam energy was measured by means of a magnetic spectrometer with a bending angle of 90 degrees. Magnetic field of the spectrometer was calibrated by an NMR method and effective bending radius was determined by a measurement of the fringing field of the magnet. Three spectra of output beam energy were measured at three points of rf voltage when the RFQ was operated at 50.2 MHz. The obtained energy spectra were shown in Fig.8.

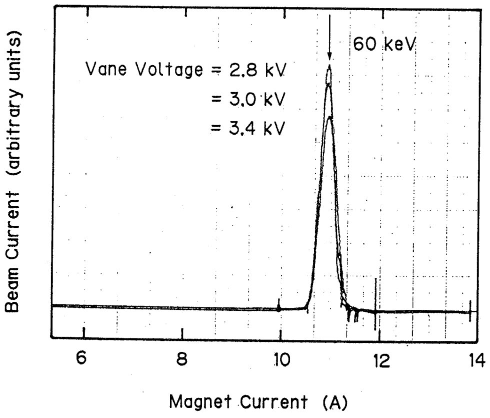

Fig.8. Energy spectra of the output beam.

In this region of the rf voltage, the shape of the spectrum does not change. The energy at the peak point of spectrum is 60 keV and agrees well with the designed value.

Concluding Remarks

As for the field distribution in this type of RFQ, there is no problem. Although the design method of the cavity structure was improved through the construction of a cold model and an accelerating model, it is necessary to estimate the resonant frequency more exactly. Through the beam test, it was confirmed that the beam was accelerated from 2 to 60 keV in accordance with the design. The exact measurement of the transmission efficiency is being prepared: the emittance of the input beam is to be measured and matched to the RFQ acceptance.

Acknowledgments

The authors wish to express their thanks to Professor A. Mizobuchi for his encouragement, Mr. S. Watanabe for his assistance in the computer work for the vane machining, and Dr. M. Yoshioka for his co-operation in the vacuum system construction. The parts of the accelerating model were manufactured at the machine shop of INS. The beam simulation and the structure design have been carried out with the computer FACOM M380 of the INS computer facility.

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