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SPLIT COAXIAL RFQ LINAC WITH MODULATED VANE

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Abstract

A split coaxial RFQ structure with modulated vanes is under development for the acceleration of very heavy ions, like uranium ions. To fix the vanes tightly to the tank and to attain accurate setting of them, a new structure is proposed: the vanes are supported by stems at several points. As a preparatory study, we have fabricated a 1/4 scaled model of a uranium machine. This model is 2 m in length, and 0.4 m in diameter. Measurements on rf characteristics have been carried out with good results: field balance among the quadrants and field flatness along the beam axis are within ±2.5%

Introduction

An RFQ accelerator structure for very heavy ions is in course of development at Institute for Nuclear Study (INS) which is a kind of split coaxial (S.C.) resonator. The split coaxial resonant cavity, invented by R.W. Mueller [1], suits to the RFQ accelerator for very heavy ions, because of its small diameter even for low operating frequency, stable resonant mode, and inherent flatness of voltage along the beam axis. Therefore, S.C. RFQ structures have been developed or investigated at GSI [2], Frankfurt [3], Argonne [4] and so on.

Various kinds of electrode structure have been proposed to produce a focussing field: modulated vanes, circular rods, drift tube with fingers and so on. At INS, the modulated vanes have been chosen for the reason that the accelerating and focussing fields produced by the electrode are expressed exactly by a simple formula [5] and that the effective use of our experience in a four vane type RFQ linac " LITL " construction [6] is made.

In order to achieve the easy assembling of vanes and the mechanical stability of structure, a multi-module cavity structure [7] is employed. In the S.C. RFQ structures proposed and developed so far, two opposite electrodes are fixed and electrically grounded at one end of a cavity and the other opposite electrodes are fixed and grounded at the other end of the cavity. That is, the electrodes are supported at only one point. On the other hand, in this multi-module cavity structure, the electrodes are supported by stems at several points.

The goal of the development of the new S.C. RFQ structure is to construct a 12.5 MHz machine for very heavy ions, like uranium. As a preparatory study, a 1/4 scaled model installed with flat vanes has been fabricated. The main purposes of this fabrication are to verify whether good mechanical stability and easy vane setting are obtained by supporting the vanes at several points, and whether voltage flatness along the beam axis is satisfactory. This paper describes design, fabrication and assembly of the multi-module cavity structure and results of the rf measurements.

Multi-Module Cavity Structure

A multi-module cavity structure is shown schematically in Fig. 1. The structure consists of cavity modules divided by two stems. One module corresponds to one resonant cavity. Horizontal and vertical vanes are supported by the vertical and horizontal stems every one module periodically and alternately. In the present case of four-module cavity, horizontal and vertical vanes are supported at two and three points, respectively, as seen in Figs. 1 and 2.

Since each module is coupled by the vanes and stems with each other, the cavity is excited in a π-mode where the phase of field changes every one module by π . In this structure, diamond-shaped plate beams

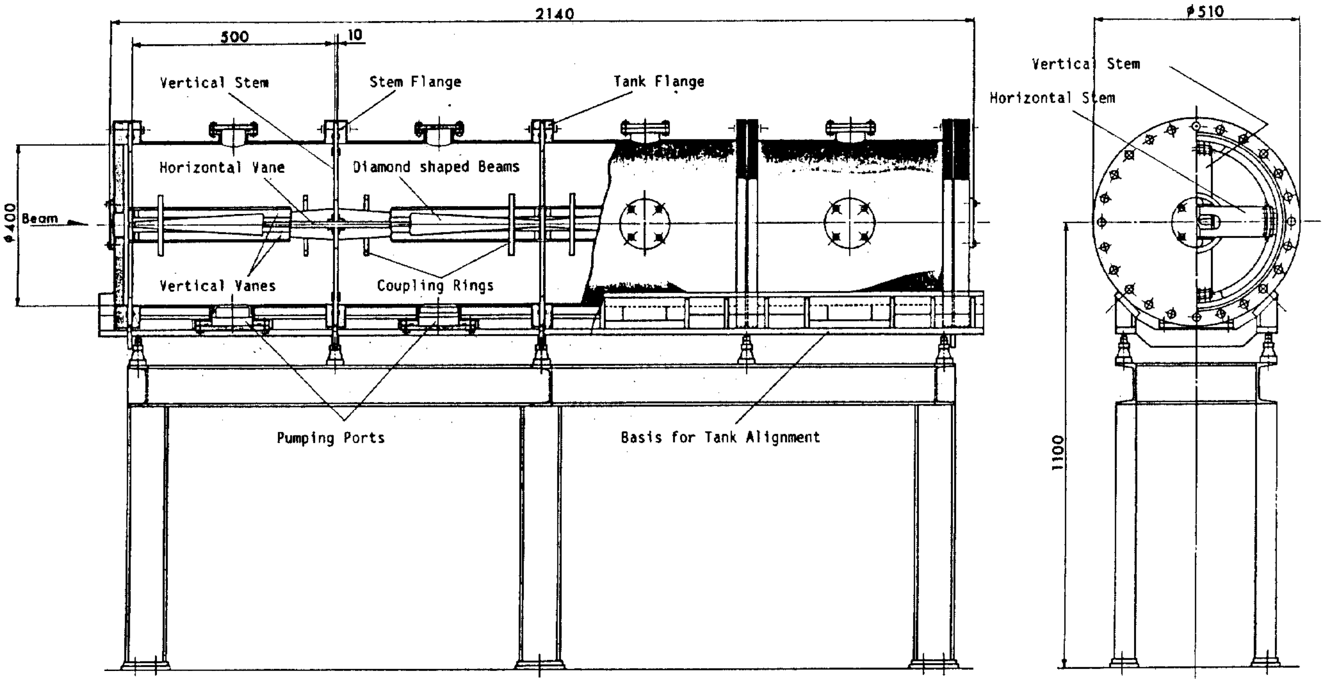

Fig. 1. A 1/4 scaled multi-module cavity structure.

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(triangular plate beams in both end modules) are used to improve the voltage flatness along the beam axis and to strengthen the support of vanes. Since the shape of the beam is simple, the manufacturing and assembling of electrodes are also easy. Furthermore, two coupling rings are used in each module, to short opposite vanes electrically and to determine a distance between the opposite vanes precisely.

Table 1

Design Parameters of $^{238}U^{4+}$ RFQ and Its 1/4-Scaled Machine

	$^{238}U^{4+}$	1/4-Scale	
Charge to mass ratio	0.01681	0.06723	
Frequency (f)	12.5	50	MHz
Kinetic energy (T)	1.68 – 45	1.68 – 45	keV/u
Normalized emittance (ε_N)	0.06	0.015	π cm·mrad
Kilpatrick factor	1.8	1.295	
Intervane voltage (V)	164.6	41.1	kV
Focusing strength (B)	4.5	4.5	
Max. defocusing strength (Δ_b)	-0.100	-0.100	
Synchronous phase (ϕ_s)	-90 – -30	-90 – -30	deg
Max. modulation (m_{max})	1.83	1.83	
Number of cells	180	180	
Vane length	800	200	cm
Mean bore radius (r_o)	1.941	0.485	cm
Min. bore radius (a_{min})	1.349	0.337	cm
Margin of bore radius (a_{min}/a_{beam})	2.0	2.0	
Transmission (0 emA)	98	97	%
(5 emA)	97	73	%
(10 emA)	94		%
Module length	200	50.0	cm
Radius of cavity	80	20	cm
Ave. radius of inner conductor	20	5	cm
Stem width	30	7.5	cm
Electrode capacitance	150	150	pF/m
Rosonant resistance per module	418	209	kΩ
Unloaded Q value	9700	4850	
rf power per module	32.4	4.0	kW
Number of Modules	4	4	
Total power	130	16.2	kW

Design

This structure has been designed based on the vane profile shown in Table 1. Dimensions of the structure are determined by compromizing with following demands: to obtain higher resonant resistance for decreasing rf power loss, to shorten the interval between the supporting points of vanes for getting the mechanical stability, and to reduce the radius of cavity for decreasing construction cost. The cavity radius and the module length are obtained by determining the electrode capacitance, the radius of inner conductor and the stem width. A concrete methode to estimate the dimensions is described in a reference paper [7].

The capacitance between vanes has been approximated by the one of four vane type RFQ, because the electric field concentrates around tips of vanes in each case of S.C. RFQ and four vane type RFQ. The capacitance is given by the resonant frequency and inductance. In the case of the four vane type RFQ, the resonant frequency is calculated by SUPERFISH and the inductance is obtained by assuming that the density of magnetic flux is constant in the cavity. Dimensions of the 12.5 MHz and 50 MHz cavities are given in Table 1.

Fabrication

All parts of the cavity are made of brass. For the low power test on rf characteristics, the tank is installed with flat vanes without modulation, and has no cooling system. In order to accomplish the vane positioning with accuracy better than ±0.1mm, the parts related to the vane positioning have been manufactured with accuracy better than ±0.025mm. The tips of flat vanes have been machined by a planer with a bite formed into a circular arc. The radius of the arc is 5 mm. No special rf contactor is used in this structure, and rf contact is accomplished only by tightening the screws.

Assembly

The vanes are assembled on diamond-shaped beams, and supported by horizontal and vertical stems. Each stem is attached to the stem flange which is placed in the flange of each module tank. The four tanks are aligned on a basis like a V-bett machined with accuracy better than ±0.025mm. At first, the vanes, the beams, the coupling rings and the stems have been assembled outside the tank to measure the accuracy of vane alignment directly. After careful positioning of the vanes to an accuracy within ±0.05mm, the horizontal and vertical vanes are locked by using assembling-tools with each other as seen in Fig. 2. The locked vanes are installed to the tanks in a state where the position of vanes is kept at the required accuracy. After installation, the assembling-tools are removed from the electrode.

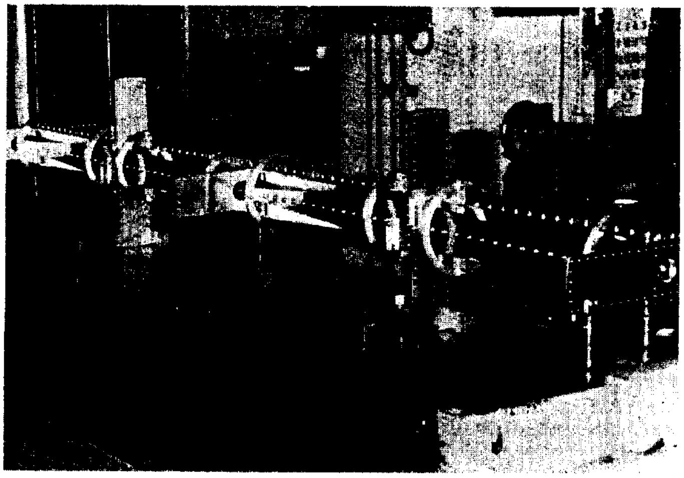

Fig. 2. Electrode assembled before installation in the tanks

RF Characteristics

Resonant Frequency

Measured resonant frequency of the fundamental mode is 37.1 MHz, much lower than designed one of 50 MHz. One reason considered is that the electrode capacitance has increased by setting the coupling rings and stems from 150 pF/m to 181 pF/m. They have been measured by using L-C meter directly. However, the decreased resonant frequency can not be explained only from this reason: the resonant frequency estimated by using 181 pF/m is 45.0 MHz. In order to examine the effect of stem on the resonant frequency, all stems have been exchanged for end walls and resonant frequency has been measured at 41.8 MHz. The difference of 41.8 MHz and 45.0 MHz must be examined from now on.

Field Distribution

Azimuthal field balance have been measured by passing a dielectric perturbator between the vane tips as shown in Fig. 3. The results show that the azimuthal field unbalance is within +2.5% and vane positioning has been achieved within ±0.1mm if the strength of the electric field is determined only by the distance of vane gap.

Longitudinal field distributions of the fundamental and higher harmonics have been measured by passing a dielectric rod, 9.5 mm in diameter and 5.5 mm in length, through the beam aperture. The error of longitudinal flatness at the fundamental mode is less than ±2.0% as shown in Fig. 4.

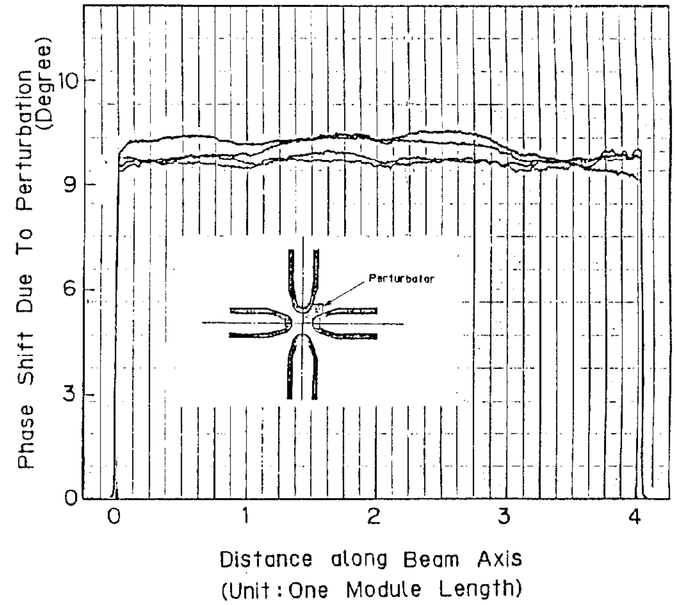

Fig. 3. Azimuthal field balance

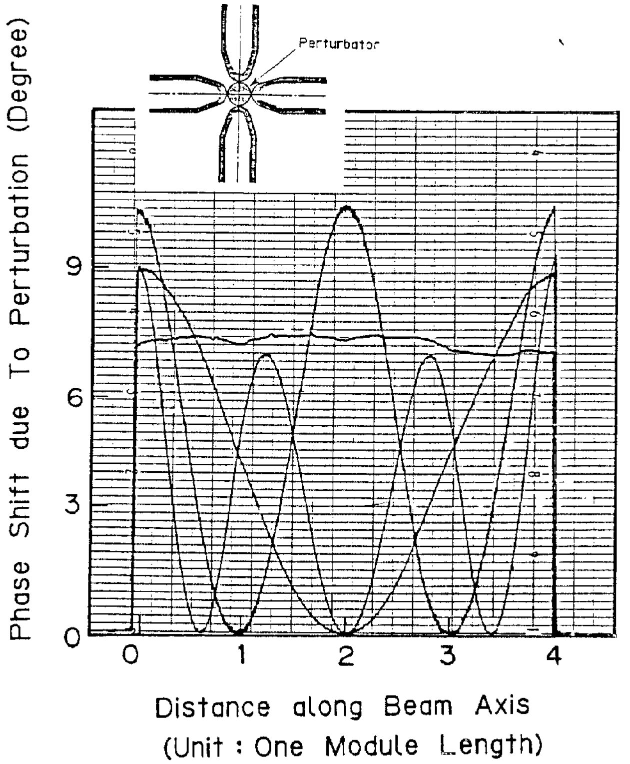

Fig. 4. Longitudinal field distributions of the fundamental mode and higher harmonics with frequencies: f_1 = 37.12MHz, f_2 = 75.09 MHz, f_3 = 132.99 MHz and f_4 = 185.36 MHz

Transverse electromagnetic field distributions have been measured by passing alternatingly a dielectric and an aluminum bead, with same radius of 1.5 mm, in a radial direction. Magnetic field is obtained by subtracting the contribution of electric field from the perturbation due to aluminum bead. The resonant frequency shift produced by only magnetic field is

$$\delta = \delta_2 - \frac{\varepsilon + 2}{\varepsilon - 1} \delta_1 , \qquad (1)$$

where δ_1 and δ_2 are resonant frequency shifts due to the dielectric and the metallic bead, respectively. The results are shown in Fig. 5.

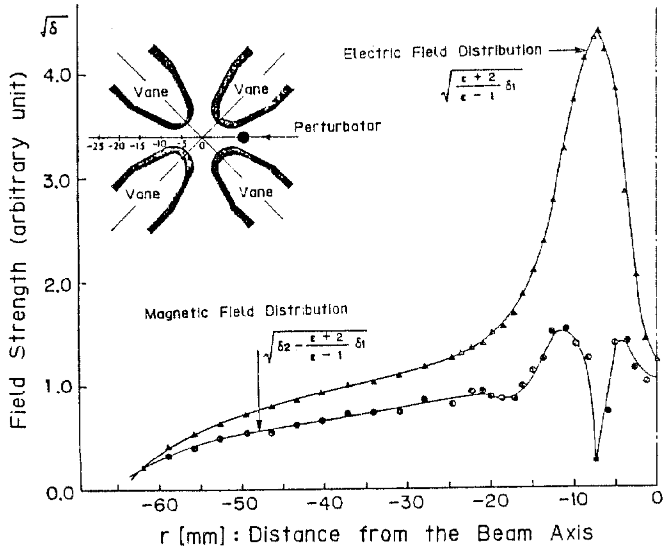

Fig. 5. Transverse field distributions at the center of first cavity

Q Value and Resonant Resistance

To feed the rf power, single loop coupler has been set at first module cavity. After matching the coupler to 50 Ω, unloaded Q value has been measured to be 2000. This value is 75 % of the estimated value. The resonant resistance has been obtained by feeding the rf voltage from a signal generator to electrode directly and by measuring the intervane voltage at feeding point and the output voltage from coupler matched to 50 Ω. The obtained value is 80 kΩ/module corresponding to 70 % of the estimation.

Discussion

From the above results of the measurements, we conclude that the multi-module cavity structure has good mechanical and electrical characteristics. After the difference of resonant frequency between a measurement and an estimation is explained experimentally and theoretically, the flat vanes will be replaced with modulated vanes and the acceleration of protons or helium ions will be tested in near future.

Acknowledgments

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