CAVITY CONSTRUCTION AND LOW POWER TESTS OF THE INS SPLIT COAXIAL RFQ FOR RADIOACTIVE NUCLEI

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Abstract

A 25.5-MHz split coaxial RFQ has been constructed at INS. The RFQ will accelerate radioactive nuclei with a charge-to-mass ratio greater than 1/30 from 2 to 170 keV/u. The cavity, 0.9 m in inner diameter and 8.6 m in length, comprises four unit-cavities. The vane electrodes have been aligned with an error less than ±40 μm before installation in the cavity tanks. After completion of the cavity, four unit cavities have been aligned with an error less than ±50 μm on the floor of an accelerator room. Low-power tests after cavity-tuning show that the longitudinal voltage flatness and the azimuthal field balance are better than ±1%, the resonant frequency is 25.46 MHz, and the unloaded Q-value is 5800 which corresponds to the resonant resistance of 22 kΩ.

Introduction

A short-lived nuclear beam acceleration facility has been under construction since fiscal year 1992 at INS. This facility is a prototype for the exotic nuclei arena of the Japanese hadron project, and aims to carry forward the R&D of isotope separator on-line (ISOL) system and heavy ion linac as well as the studies on nuclear astrophysics, *etc.* The facility comprises an SF cyclotron (primary accelerator), an ISOL and a heavy ion linac complex (post-accelerator). The post-accelerator comprises a 25.5-MHz RFQ, a charge-stripper section with a carbon foil, and a 51-MHz interdigital-H linac; and accelerates ions with a charge-to-mass ratio (q/A) greater than 1/30 from 2 to 1046 keV/u [1].

As the above RFQ, a 25.5-MHz split coaxial RFQ (SCRFQ) has been constructed on the basis of the studies of a prototype (25.5 MHz, $q/A \geq 1/30$, 1→45.4 keV/u, 0.9 m in inner diam., 2.1 m in length) [2]. The INS-type SCRFQ has the following features: four modulated vanes are used to generate ideal quadrupole and accelerating fields; and a multi-module cavity structure is employed to install the modulated vanes in the split coaxial resonator precisely and firmly. Design parameters of the SCRFQ are summarized in Table 1. This paper describes the cavity construction and the low power tests.

TABLE 1
Design parameters of the 170 keV/u SCRFQ

Frequency (f)	25.5 MHz
Charge-to-mass ratio (q/A)	$\geq$ 1/30
Kinetic energy (T)	2 → 172 keV/u
Normalized emittance (ε_N)	0.6π mm·mrad
Vane length (l_V)	8.585 m
Number of cells (radial matcher)	172 (20)
Kilpatrick factor (f_K)	2.49
Intervane voltage (V)	108.6 kV
Mean bore radius (r_0)	0.985 cm
Min. bore radius (a_{min})	0.539 cm
Margin of bore radius (a_{min}/a_{beam})	1.2
Focusing strength (B)	5.5
Transmission efficiency*	
at 0 mA input	91.4%
at 5 mA input	86.0%

*(for q/A=1/30 ions)

Cavity Construction

Cavity structure

The cavity (0.9 m in inner diam., 8.6 m in length) comprises four unit cavities, whose structure is nearly same as that of the prototype. An important difference is vane coupling rings are not used in the new cavity. We used the prototype cavity as the fourth unit cavity and fabricated newly three unit cavities. The structure of the unit cavity is shown in Fig. 1. The material of the tank is mild steel, whose inner wall is plated with copper to a thickness of 100 μm, and that of the inner structure except the vanes is oxygen-free copper. The vanes are made of chromium-copper alloy.

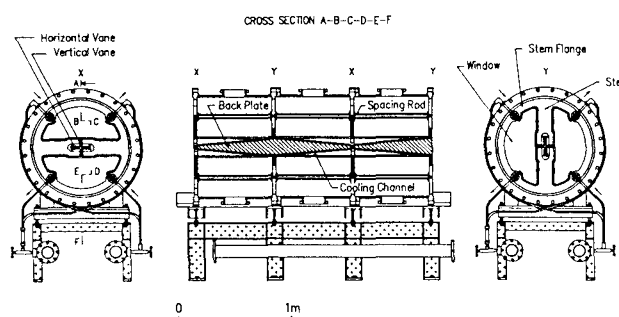

Figure 1: Structure of the unit cavity.

One unit cavity comprises three module-cavities. The module length, 0.7 m, was determined so as that the droop of the vanes due to the gravity might not exceed 35 μm, and the cavity diameter, 0.9 m, so as that the resonant fre-

TABLE 2
Rf and geometrical parameters of the cavity

Frequency (f)	25.46 MHz
Cavity length	8.6 m
Cavity Inner diameter	0.9 m
Vane thickness	3 cm
Stem width	15 cm
Stem thickness	3 cm
Outer diameter of spacing-rods	3.8 cm
Total capacitance (C)	1650 pF
Total inductance (L)	23.7 nH
Resonant resistance (R_P)	22 kΩ
Intervane voltage (V) (for q/A=1/30)	108.6 kV
Peak power loss (P) (for q/A=1/30)	270 kW

quency might be 25.5 MHz. The electrodes consist of the vanes and spear-shaped back plates. The vanes are bolted on spear-shaped back plates, which are used for stabilizing the vanes mechanically and for improving the Q-factor. The vertical vanes are fixed to the cavity cylinder with horizontal stems at two positions, and the horizontal ones are fixed with vertical stems at other two positions. The stem-flanges are arranged at equal distances by four spacing-rods. The vanes were aligned with an accuracy better than ±40 μm before installation in the unit-cavity tank.

The unit cavity is cooled by eleven water channels running in parallel. Three channels are for cooling the cavity cylinders, and eight channels for the stem flanges, the spacing rods, the stems and the back plates. The flow rate of each channel was determined so as that the temperature increase of the water might be less than 1.4°C under a 30% duty operation with a peak power of 90 kW. Total flow rate for one unit cavity is about 290 l/min. For cooling the stems and the back plates, copper pipes, 12.7 mm in outer diam. and 0.8 mm in thickness, were soldered along the stems and around the back plates.

When the whole cavity was installed in an accelerator room at INS, four unit-cavities were aligned with an error less than ±50 μm by means of a water level and a telescope. Main geometrical and rf parameters of the whole cavity are summarized in Table 2. The rf parameters are the measured values after tuning the cavity.

Vane structure

The transverse radius of curvature of the vane-tip (ρ_T) is variable in the low-energy part, about 1 m long in the first unit cavity, and the ρ_T is constant at the mean bore radius (r_0) in the high-energy part. The vanes in the first unit cavity were machined by means of a three-dimensional cutting technique, and for the other vanes a two-dimensional cutting technique was adopted. For each vane-tip geometry, we made a correction on the aperture parameter a and modulation m (A_{10} correction) to bring the actual field close to an ideal one [3].

Low Power Tests

Capacitance measurements

On the way of the cavity construction, we measured the inter-electrode capacitance for each of the unit cavities, from the first to the fourth, and obtained 395, 406, 407 and 408 pF, respectively. The smaller capacitance in the first unit cavity is due to a flared vane configuration of the radial matcher.

Rf characteristics before tuning

After completion of the cavity, low-power tests in the atmosphere were conducted for cavity tuning, field-balance measurement and Q-value measurement. At first, we measured the rf characteristics of the cavity before its tuning in order to estimate the inductances used in an equivalent-circuit analysis of the SCRFQ. When the stem-flange windows are completely open except the both-end ones which are completely closed, the resonant frequency of the fundamental mode is 25.562 MHz, and the frequencies of the first-through-third harmonics are 30.935, 42.468 and 56.611 MHz, respectively; the unloaded Q-value is 6390 at the fundamental mode. On the other hand, when the stem-flange window between the 6th and 7th modules is completely closed, the resonant frequency of the fundamental mode is 25.895 MHz.

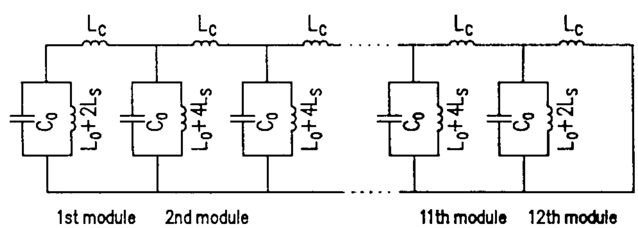

Figure 2: Equivalent circuit of the 12-module cavity.

When all stem-inductances are assumed to be equal to each other, an equivalent circuit of the 12-module cavity is approximately illustrated as shown in Figure 2. The total inductance of the cavity (L) is given by the tank inductance per module cavity (L_0) and the stem inductance per stem flange (L_S) as follows:

$$L = \frac{(L_0 + 2L_S)(L_0 + 4L_S)}{12L_0 + 28L_S} . \tag{1}$$

The coupling inductance per module (L_C) is obtained from the following dispersion function:

$$f = \frac{1}{2\pi\sqrt{LC}} \left[\frac{12L}{L_C} \left(\frac{\pi}{12} n \right)^2 + 1 \right]^{1/2} , \tag{2}$$

where C is the total capacitance, 1616 pF, and n is the order of harmonics. From above rf measurements, we estimated L_0 = 213.3 nH, L_S = 20.59 nH, and L_C = 45.45 nH.

Tuning of the cavity

We tuned the resonant frequency and the longitudinal voltage distribution by changing locally the inter-electrode capacitance and the stem inductance. For changing the capacitance, C-tuners of the copper plates (170 or 120 mm in height, 30 mm in width, 3 mm in thickness) were attached on the back-plates so that a plate confronted a stem with a distance of 25 mm. We changed the stem inductance by adjusting the area of the stem-flange windows. The longitudinal voltage distribution before tuning is shown in Fig. 3. For the measurement, a Teflon perturbing object of a square plate, $30 \times 30 \times 8$ mm^3, was moved along two vanes used as a guide, as shown in Fig. 3. The observed spikes are due to the stems. The inter-vane voltage droops at the cavity ends. This is caused by the smaller capacitance in the first module and the reduced inductance in the 1st and 12th modules, where the stem-flange windows at the whole cavity ends are closed.

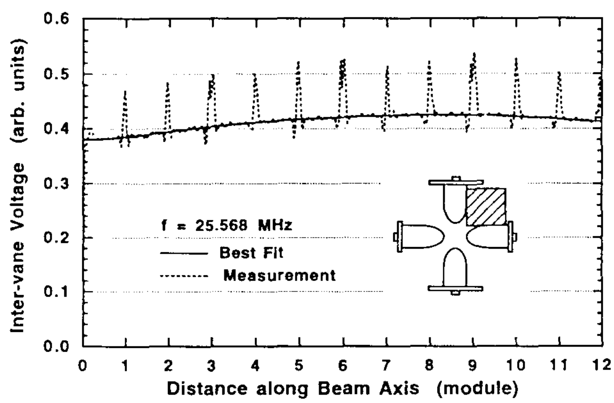

Figure 3: Longitudinal voltage distribution before tuning.

In order to compensate this droop, C-tuners (170 mm in height) were installed in the 1st module, and other tuners (120 mm in height) in the 2nd and 12th ones; the number of tuners is four per module. Further fine tuning was performed by adjusting the stem inductance between the 6th and 7th modules. After the tuning, the longitudinal distribution is flat within $\pm 1\%$ as shown in Fig. 4.

Azimuthal field balance was measured with a Teflon perturbing object, 14 mm in length and 9.5 mm in diam., as shown in Fig. 5. Four curves corresponding to electric fields in the quadrants are drawn in the figure and they are almost overlapping each other. The resulting azimuthal imbalance is within $\pm 1\%$. The resonant frequency after tuning is 25.46 MHz, and the unloaded Q-value is 5800. From their values, the resonant resistance is derived to be 22 kΩ.

Concluding Remarks

Through the cavity construction and the low power tests, it has been verified that there is no problem even if the vane coupling rings are not used. The low power tests showed following results: 1) the capacitance reduction of the first

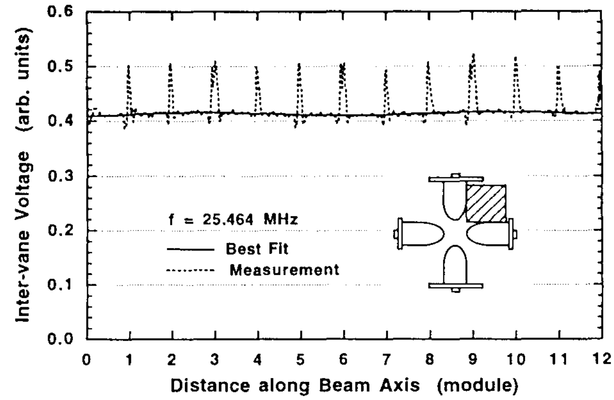

Figure 4: Longitudinal voltage distribution after tuning.

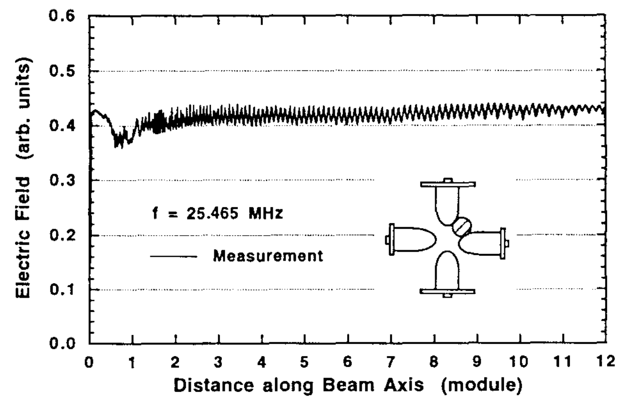

Figure 5: Azimuthal field balance after tuning. Four curves for the quadrants are plotted

module due to the radial matcher affects significantly on the longitudinal voltage distribution. 2) longitudinal distribution is easily controlled by attachment of the simple C-tuners and by adjustment of the stem inductance. 3) after tuning, errors of the longitudinal voltage and azimuthal field balances are within $\pm 1\%$. We will accelerate a first beam at the end of this fiscal year.

Acknowledgments

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