# A PROTON ACCELERATING MODEL OF URANIUM RFQ

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## Abstract

A split coaxial RFQ with modulated vanes has been developed for the acceleration of very heavy ions, like uranium ions. In order to achieve the easy assembling of vanes and the mechanical stability of the structure, a multi-module cavity structure is employed. A proton accelerating model is under construction 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. The model can accelerate protons from 2 to 60 keV at an rf frequency of 50 MHz.

## Introduction

A split coaxial RFQ linac with modulated vanes is under development for acceleration of very heavy ions at Institute for Nuclear Study (INS)[1-5]. A 1/4-scaled cold model with flat vanes has been constructed for investigating the mechanical and rf characteristics. In order to achieve the presice vane alignment and good mechanical stability, a multi-module cavity structure was employed. Although the required field distributions were obtained, the measured resonant frequency was different from the expected value. By investigating the rf characteristics on this model experimentally and theoretically, the cause of the discrepancy between the measured and expected resonant frequencies was clarified and the estimation methods of rf parameters such as the resonant frequency, the resonant resistance and the Q-value were improved. Furthermore, the dispersion characteristic of the resonator and the longitudinal field distributions in the fundamental and higher harmonics modes were predicted qualitatively well by introducing an equivalent circuit analysis.

Based on the above basic research, the cold model is converted into a proton accelerating model by replacing the flat vanes with the modulated vanes. This model can accelerate a proton beam from 2 to 60 keV at an rf frequency of 50 MHz. The total length and diameter of the cavity structure are about 200 and 40 cm, respectively. The purpose of the proton accelerating test is to evaluate the overall performance of the RFQ of this type.

## Outline of the Model

### Accelerating Structure

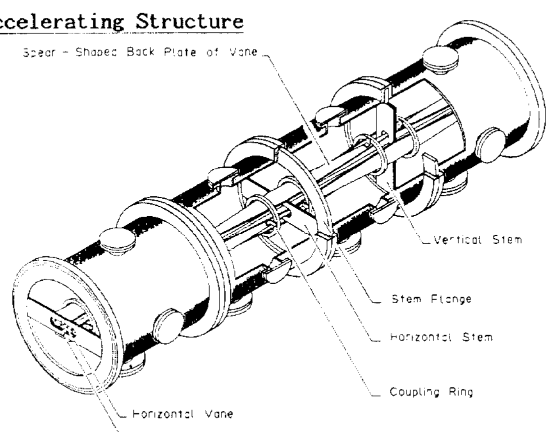


Fig.1. A four-module split coaxial RFQ.

A multi-module split coaxial RFQ has been employed as an accelerating structure of the proton model. The structure is divided into four modules by the horizontal and vertical stems which support vertical and horizontal vanes as shown schematically in Fig.1.

Each module corresponds to a resonator and the multi-module cavity structure is a chain of resonators. Since each module is strongly coupled together on rf by the vanes and stems with each other, the field balance among the modules is very stable. Though the multi-module cavity structure has resonances of the higher harmonics mode in addition to the fundamental mode, there is no deflection mode near the fundamental mode. The resonance characteristics are explained well by an equivalent circuit analysis in which the lumped and distributed constants are combined as shown in Fig.2.

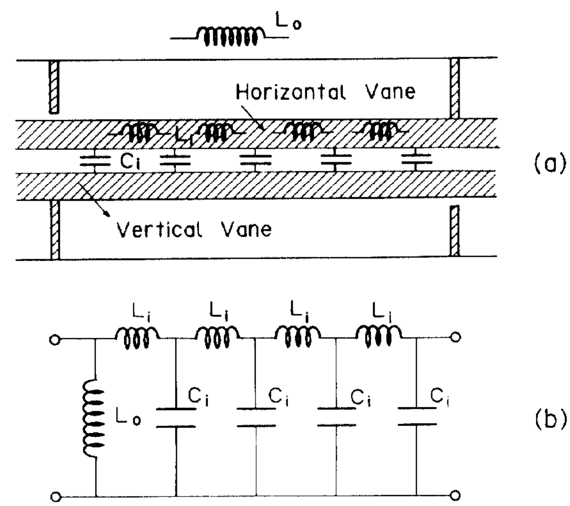


Fig.2. a) Relation between the cavity structure and the equivalent circuit elements.
b) An equivalent circuit for the unit module expressed by the lumped constant $L_0$ and distributed constants $L_i$ and $C_i$.

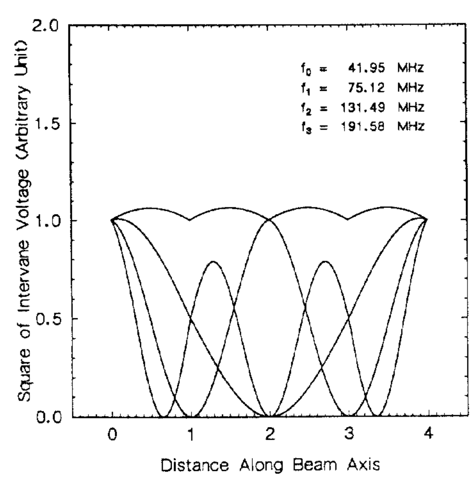


Fig.3. Longitudinal voltage distributions calculated on the cold model.

Longitudinal voltage distributions predicted by this analysis on the cold model are shown in Fig.3.

The resonant frequency of the structure is determined mainly by the tank radius, the module length, the stem width, the mean width and thickness of the spear-shaped back plate of the vane and the capacitance between vanes. In order to determine such parameters, a new estimation method of the inductance is used which has been introduced for interpretation of the experimental results with respect to the rf characteristics on the cold model. Design parameters of the structure are summarized in table 1.

Table 1. Design parameters of the structure.

| | Design | |
|---|---|---|
| Number of Modules | 4 | |
| Length of one module | 51.0 | cm |
| Radius of cavity | 20.0 | cm |
| Stem width | 14.0 | cm |
| Stem thickness | 1.0 | cm |
| Max. width of spear-shaped plate | 14.0 | cm |
| Min. width of spear-shaped plate | 2.8 | cm |
| Thickness of spear-shaped plate | 0.9 | cm |
| Total inductance | 27.7 | nH |
| Electrode capacitance | 369 | pF |
| Rosonant resistance | 34 | kΩ |
| Unloaded Q value | 3910 | |

The tanks are made of brass. The inner conductor and stems are made of aluminum alloy. Either of the inner conductor and tanks is not cooled by water. In this model, any special contactor is not used when the inner conductor is assembled and mounted to the tanks.

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. Rough tuning of the structure is performed by adjusting the stem inductance, that is, by changing the stem width. Fine tuning is done by means of loop tuners in each module.

## Vane Parameters

Table 2. Design parameters of the vane.

| | Design | |
|---|---|---|
| Frequency ($f$) | 50 | MHz |
| Kinetic energy ($T$) | 2.00 → 59.6 | keV |
| Normalized emittance ($\varepsilon_N$) | 0.03 | π cm·mrad |
| Intervane voltage ($V$) | 2.9 | kV |
| Focusing strength ($B$) | 3.8 | |
| Max. defocusing strength ($\Delta_b$) | -0.075 | |
| Synchronous phase ($phi_s$) | -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 | % |

An operating rf frequency is 50 MHz and the proton beam is accelerated at inter-vane voltage of 2.9 kV from 2 to 60 keV. Main vane parameters are summarized in table 2. In the case of a split coaxial RFQ, the voltage potential of $(V/2)\cdot \sin(\omega t+\varphi)$ is generated on the beam axis. A radial matching section is designed in such a way that the energy spread of the beam does not increase when the beam passes through the radial matching section. Linear and sinusoidal ramps are considered as gradient of the potential along the beam axis in the radial matching section. In the present model, the linear ramp has been adopted as in the case at GSI[6,7]. The relation between the beam transmission and the length of the input radial matching section has been simulated by means of a PARMTEQ. The result is shown in Fig.4. As seen in Fig.4, the length of the radial matching section is required to be even times of the unit cell length. A length corresponding to 10 cells has been chosen in the present case.

Since the output radial matching section is not used in this model, the effect of the axial potential on the output beam will be examined through the beam acceleration test.

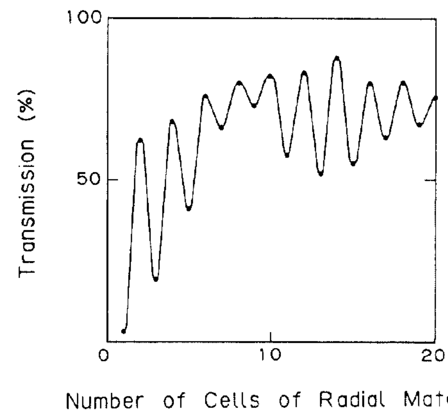


Fig.4. Relation between the transmission and the length of the radial matching section.

## Test Stand

Layout of the test stand is shown in Fig.5. Proton beam is produced by a compact ion source of ECR type which works by the microwave of 2.86 GHz. The beam, which passed through an ion separating magnet, is matched to phase space of the RFQ by means of two sets of the einzel lenses. Energy of the output beam is measured by a magnetic spectrometer system. The energy resolution of the system is 0.8%. The beam current is measured by a Faraday cup.

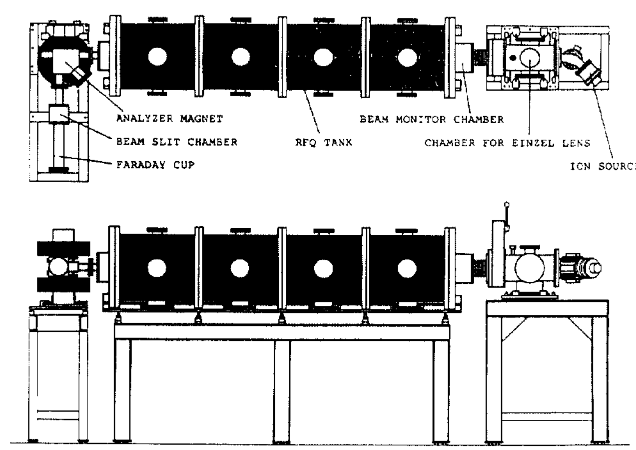


Fig.5. Test stand of the proton accelerating model.

In this output beam diagnostic system, any beam focussing element is not used since the beam diameter and divergence at the RFQ exit are relatively small, namely

4 mm and 26.5 mrad, respectively. In order to accelerate the proton beam, an rf power of about 200 watts is required. The power amplifier of 500 watts is available for the present test.

## Status of the Construction

Modulated vanes have been manufactured with an NC lathe at the INS machine shop. A ball end mill is attached to the chuck of the lathe and the vane is gripped with a special vise which is attached to the tool post of the lathe. A state of the vane cutting is shown in Fig.6. Each vane of 205 cm long is completed by connecting 11 short vane pieces since the maximum length, that this NC machine can cut, is 20 cm. The ball end mill is 10 mm in diameter. The vanes have been machined at a 1 mm increment along the longitudinal axis. Maximum amount of the over-cutting is 168 $\mu m$ at the place of cell No. 139.

In order to verify an accuracy of the vane alignment before the installation into the tanks, four vanes have been assembled by the spear-shaped back plates, the stems and the coupling rings as shown in Fig.7. After the vane alignment has been achieved with an accuracy better than $\pm 50$ $\mu m$, the inner conductor has been installed in the tanks as shown in Fig.8.

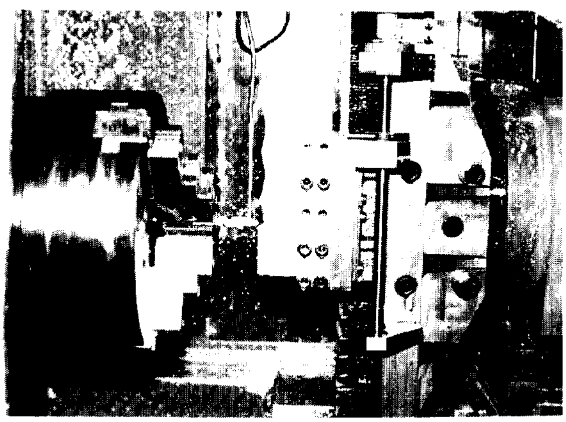

Fig.6. Vane machining.

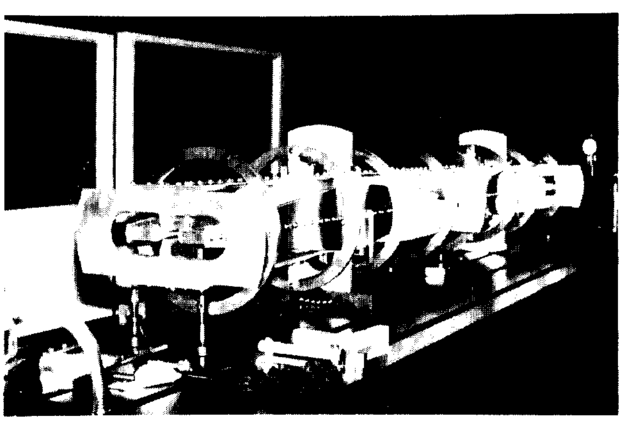

Fig.7. Assembled inner conductor outside tanks.

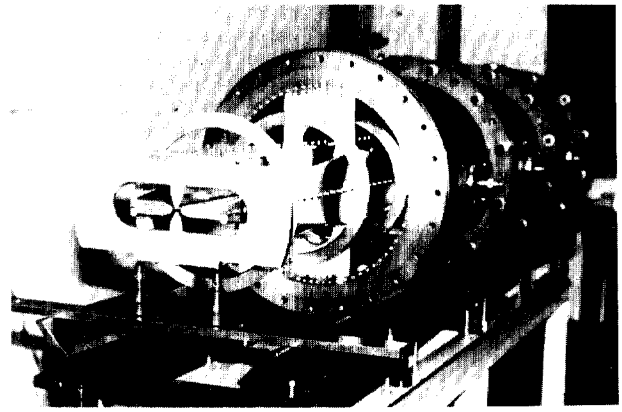

Fig.8. Installation of the inner conductor in the tanks.

## Acknowledgments

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