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Model Study of a 4-Rod Structure of RFQ Linac

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RFQ linac for heavy ion acceleration was investigated. Longitudinally uniform quadrupole field was generated by the 4-Rod electrodes. The resonant frequency can be changed by varing the length and the position of supports of electrodes. Transverse electric field distribution was studied. The Q-value of 1500 was obtained.

KEY WORDS: RFQ linac/4-Rod structure/

1. INTRODUCTION

RFQ linacs so far constructed are mainly 4-vane type. Because the resonant frequency of 4-vane type RFQ is inversely proportional to the cavity diameter, a cavity of over 1 m diameter is necessary to get the resonant frequency of lower than 50 MHz for heavy ion acceleration.

The 4-Rod structure, which consists of four electrode rods, has been developed by groups of Frankfurt University1) and GSI.2),3) The small size and low resonant frequency of the cavity are preferable for heavy ion acceleration.

We constructed 4-Rod RFQ models and studied RF characteristics to design a Boron ion accelerator.

2. CONDITION OF HEAVY ION ACCELERATION

The upper limit of the RFQ frequency for ion acceleration is determined by machining accuracy of electrode modulation and by electric focusing strength.

The machining accuracy limits the froquency as

$$\beta\lambda/2 \geqq l, \qquad \text{......(1)}$$

where l is the shortest cell length we can fabricate, β is a ratio of ion velocity v to light velocity c, and λ is wave length in free space. When l is 3 mm and $^{11}B^{+}$ ions are injected at 30 kV ($\beta=0.00242$), the resonant frequency f is calculated to be less than 121 MHz by the eq. (1).

The focusing strength B, which is dimentionless, is usually set to be between 4 and 6 for heavy ion RFQ linacs. B is expressed by the following equation;4)

$$B = \frac{q\,\lambda^2\,V}{M\,c^2\,r_0^2}, \qquad \text{......(2)}$$

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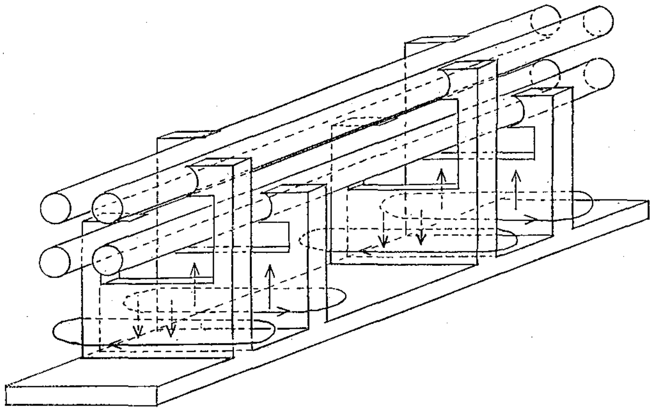


Fig. 1. A unit of 4-Rod structure

where q is the charge state, M is the mass number, V is the maximum voltage between electrodes and r_0 is the average bore radius of RFQ electrodes. We have determined that r_0 is 8 mm and that V is 95 kV. When B is greater than 4, the frequency must be lower than 57 MHz according to the eq. (2). The pole-tip surface field, V/r_0, is 1.3 times of Kilpatrik's limit. We chose 50 MHz as a operating frequency.

3. 4-ROD STRUCTURE

Fig. 1 shows a unit of 4-rod structure. If we regard each diagonaly positioned pair of quadrupole rods as a transmission line over the base plate, the structure is considered to be two transmission lines coupled by the inductance of supports and the capacitance between the lines. Quadrupole field is generated when the two lines are excited with phase difference of π. The directions of electric current and magnetic field for the quadrupole excitation are indicated in Fig. 1. Because the inductance between the

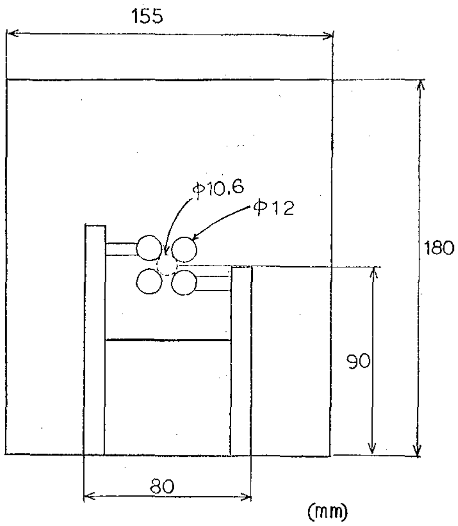


Fig. 2. Cross section of model A

two transmission lines can be controlled by the support height and distance, the resonant frequency can be easily varied without any major change in size.

4. FABRICATION OF RFQ MODEL

Two half scale models were made. The resonant frequencies were about 100 MHz. Model A was constructed to investigate the fundamental characteristics of 4-Rod structure. Model B was made for RF power test. Both models had unmodulated electrodes.

Model A was a one-unit aluminum structure situated in a copper tank. The

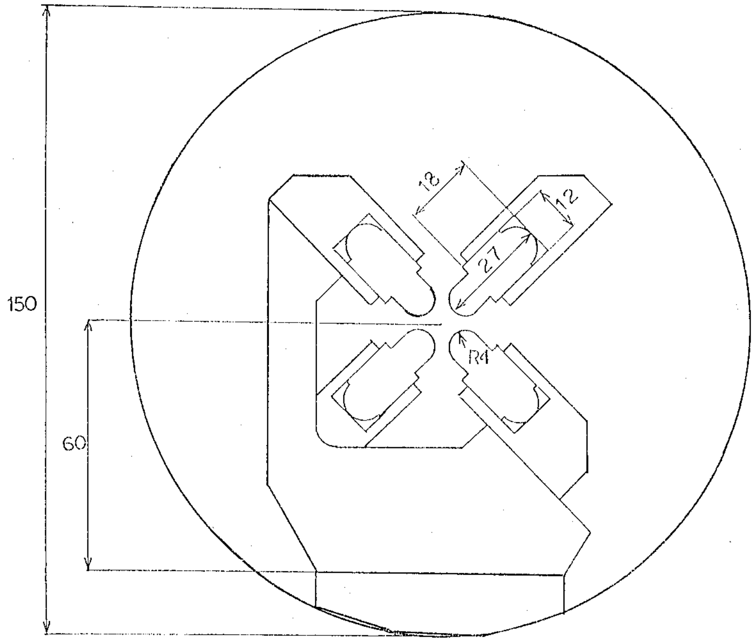


Fig. 3. Cross section of model B

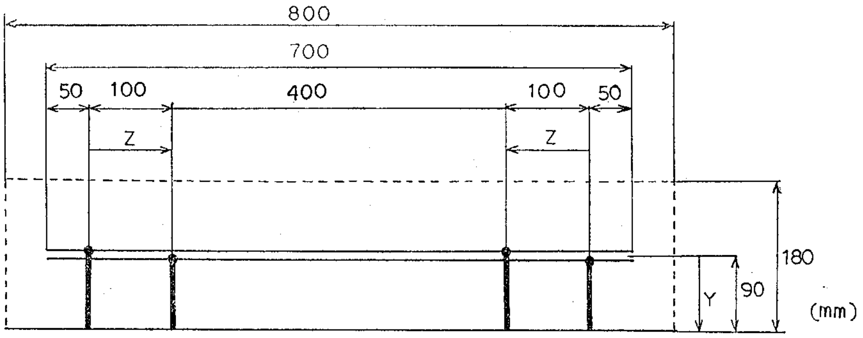


Fig. 4. A support configuration of model A

cross section is shown in fig. 2. The structure was so simple that the height of supports and the distance between them could be easily changed. Model B was made of copper and had enough strength for precise alignment (fig. 3). Electrode position was adjustable in radial direction and was able to be fixed tightly to supports with good contact by joint clumps. The structure was assembled on a table and placed in a cylindrical tank of 150 mm diameter. Cooling channels could be located at the thick part of electrodes, and go through the supports and the base plate to the outside of the cavity. Bore radius of electrodes was 4 mm and other dimensions are shown in fig. 3.

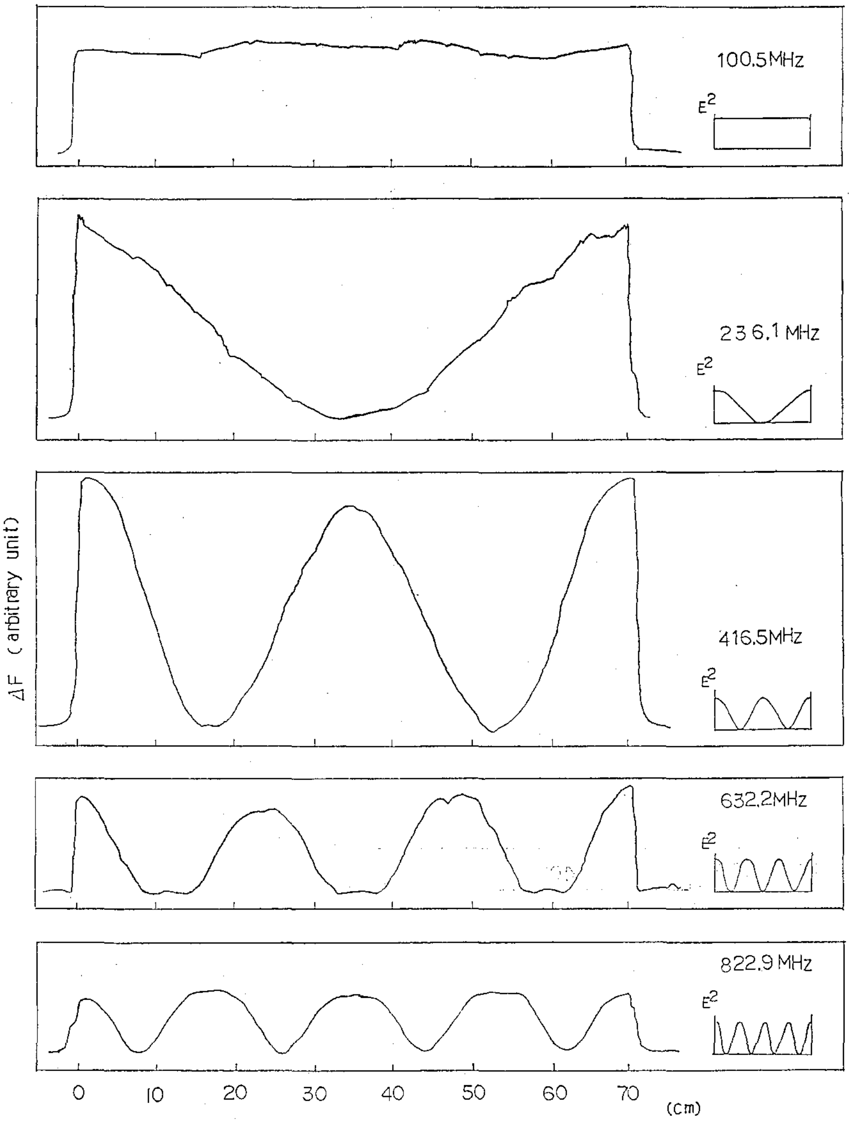


Fig. 5. Typical longitudinal distributions of frequency shift

5. RESULTS OF RF FIELD MEASUREMENT

1) Model A

An example of support configuration of model A is illustrated in fig. 4. The dotted lines show the tank wall. The solid circles are the joints between electrodes and supports. Resonant frequencies were measured by a standard signal generater and a powermeter. Distributions of electric fields were measured by the bead-perturbation method. Fig. 5 shows the typical longitudinal distributions of frequency shift at several resonant frequencies with the configuration shown in fig. 4. Resonance modes are identified as illustrated in the same figure. The resonances were identified to be quadrupole excitation by measuring the phase of electric field near the electrodes. The despersion curve for the quadrupole mode is shown in fig. 6.

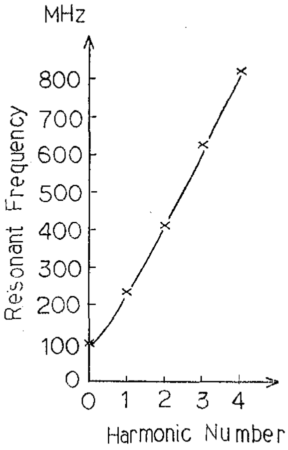


Fig. 6. Dispersion curve for quadrupole mode of model A

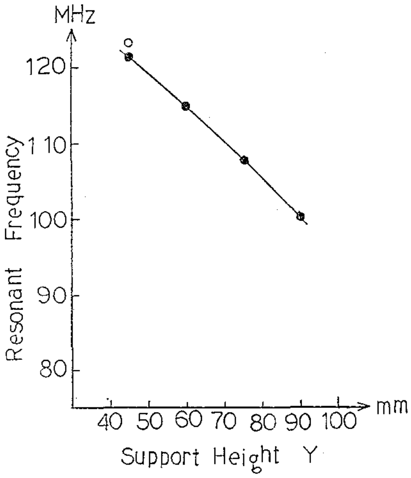


Fig. 7. Variation of 0-mode frequency as a function of support height

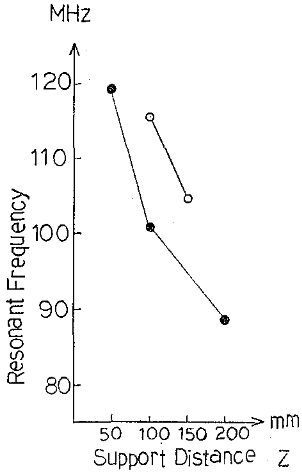


Fig. 8. Variation of 0-mode frequency as a function of support distance

In fig. 7, variation of 0-mode frequency is plotted as a function of the support height y, which is the distance between the beam axis and the base plate. In case of y=45 mm, the frequency was also measured with the tank height of 80 mm, and is shown by the open circle. Although 50% change of the support height caused 20% frequency shift, the size of the tank was found to be not critical. Fig. 8 shows the variation of 0-mode frequency as a function of the support distance z. Open circles are results at y=90 mm, and solid circles are those at y=60 mm.

2) Model B

Fig. 9(a) shows a one-unit configuration of supports for model B. The longitudinal distribution of electric field for 0-mode (85 MHz) is shown in fig. 9(b). The electric field was enhanced in the middle of the unit. Fig. 10(a) shows another configuration, where supports were placed in equal intervals. The corresponding field distribution for 0-mode (72 MHz) has become uniform as shown in fig. 10(b).

Two-unit configuration was assembled as shown in fig. 11(a). The longitudinal field distribution for 0-mode (117 MHz) is shown in fig. 11(b). The electric field was enhanced slightly in the middle of the unit, but the deviation was less than 4%. The following measurements were done with this configuration.

The longitudinal electric field distributions of higher harmonic resonanses were measured. The harmonic number was assigned for each resonance by counting nodes. In fig. 12, the resonant frequencies are plotted as a function of the harmonic numbers. The points of mark x are considered to be quadrupole excitation mode. The transverse electric field distributions were measured. The electrode distance a, b in fig. 13 were changed and the results were shown in fig. 14. The displacement of

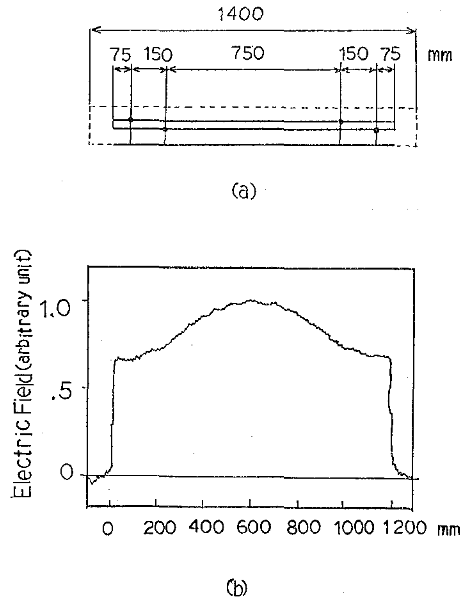
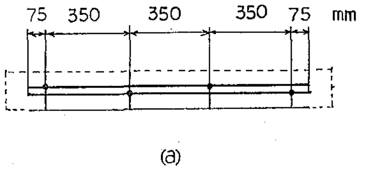


Fig. 9. (a) A one-unit configuration of supports for model B
(b) Corresponding longitudinal electric field distribution for 0-mode



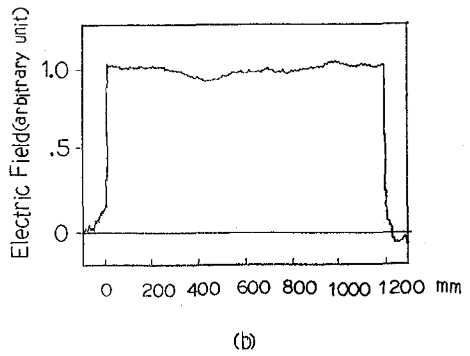
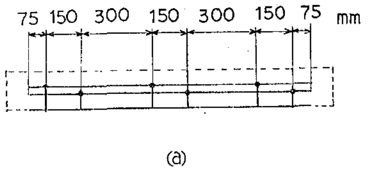


Fig. 10 (a) Another one-unit configuration of supports for model B
(b) Corresponding longitudinal electric field distribution for 0-mode



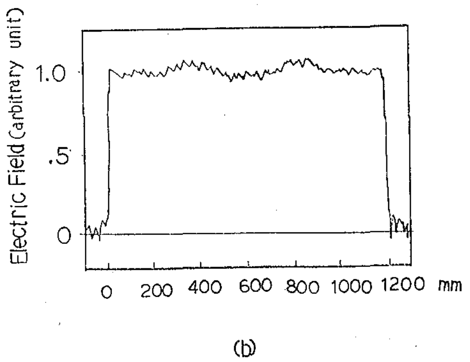


Fig. 11. (a) A two-unit configuration of supports for model B
(b) Corresponding longitudinal electric field distribution for 0-mode

electrodes was reflected in the symmetry of the electric field.

The measured Q-value was 1500 for 0-mode excitation. From the Q-value and the frequency shift of the bead-perturbation, we found that inter-electrode voltage of 38 kV, which is necessary for $^{11}B^{2+}$ acceleration, can be achieved with the input power of 51 kW. There is some possibility to reduce the power requrement, such as improvement of surface finish and electric contact and optimization of geometry.

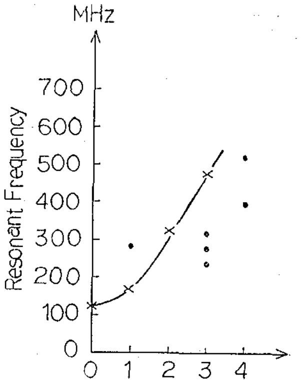


Fig. 12. Dispersion curve for model B

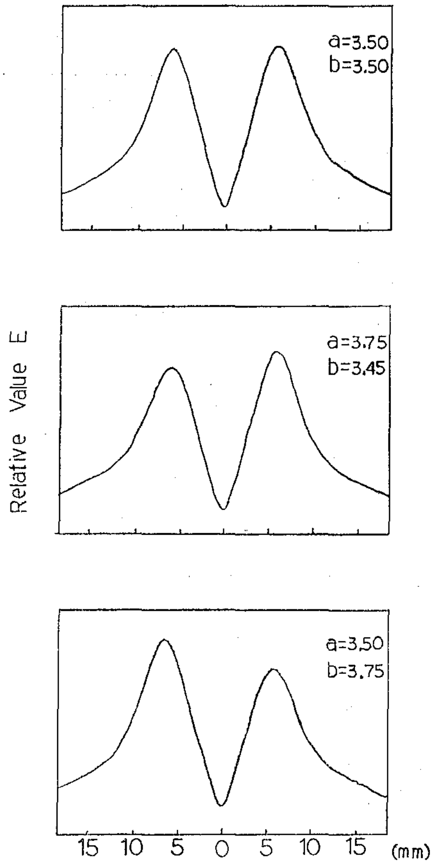


Fig. 14. Transverse electric field distribution

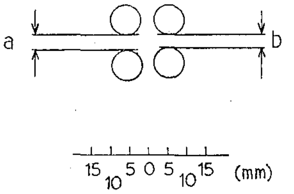


Fig. 13. Schematic of electrodes

6. CONCLUSION

Using the 4-Rod structure, low frequency cavities of small diameter were constructed. A cavity of 3 m length and of only 0.4 m diameter can accelerate $^{11}B^{+}$ to 2 MeV, which is less than half of diameter compared with a 4-vane cavity. For heavy ion acceleration, RFQ linac of the 4-Rod structure is very attractive.

7. ACKNOWLEGEMENT

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