TEST OF A 473 MHZ FOUR-ROD RFQ[†]

Reza Kazimi, F. R. Huson, and W. W. MacKay
Department of Physics, Texas A&M University and Texas Accelerator Center
TAC, 4802 Research Forest Dr., Building 2, The Woodlands, TX 77381

Abstract

A 500 keV 473 MHz RFQ using a new type of four-rod design has been fabricated at Texas Accelerator Center. Our purpose is to test the structure by accelerating a 10 mA beam of H^- ions through the RFQ. This paper presents the structural characteristics of the RFQ, the beam dynamics parameters, the tests of a cold model , and the results of the low power rf tests of the RFQ.

Introduction

The four-rod RFQ structure invented at Frankfurt[1] not only has been a viable alternative to the four-vane structure, but also offers many advantages such as simplicity of structure and elimination of the dipole mode. However, the four-rod design has not been studied extensively for frequencies much above 200 MHz. Higher frequencies (400 to 500 MHz) are desirable for pre-injectors of proton machines. By introducing a small variation to the Frankfurt geometry we have developed a four-rod type design for these higher frequencies.[2,3] After designing several simple test models, checking them using computer codes such as MAFIA[4], and obtaining desirable results from cold model measurements, we set out to make a test RFQ at 473 MHz and to accelerate a 10mA of H^- ion beam from 30 keV to 500 keV. (The reason for 473MHz is the rf power source.) We first made a short cold model of the structure to check our calculations and to discover and solve possible problems in construction and assembly. Next, we made a full beam dynamics design for a short low power RFQ. Pieces were machined and assembled and a cold test of the RFQ was done. This paper will discuss the design of the structure, the test results of the cold model, the beam dynamics design, and the cold test of the final RFQ.

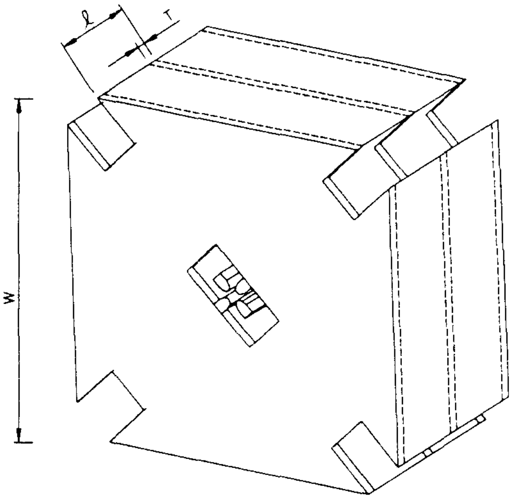

Figure 1. Two modules of the 473 MHz structure.

The structure

The structure is made of a series of modules. Figure 1 shows two modules next to each other. Each basic module of length ℓ consists of two square plates of thickness T and width W supporting the four rods. Each supporting plate is connected to two opposing rods. Four rectangular plates cover the sides of the structure with the corners of the structure being left open to give better vacuum quality. The corners can be left open for the following reasons: First, the diagonal planes going through the opposing corners are the symmetry planes of the structure. Therefore, there should be no currents crossing these planes. In other words, the $\vec{B}$ field is perpendicular to these planes. Second, the fields are weak at the corners, so leaving the corners open should not appreciably change the resonant frequency or the Q. Figure 2 shows the magnetic field for a cross section at the middle of a module ($z = \ell/2$), showing that $\vec{B}$ is negligible at the corners.

Since the two opposing rods are attached to the same plates at many points through the structure, the dipole mode, which appears when the two opposing rods oscillate at different voltages, is not a problem. In other words, there is no mixing of unwanted dipoles mode with the desired quadrupole mode. This is an advantage that all the four-rod type structures share over the four-vane types in which the mode mixing could be a serious problem.

[†] TAC at HARC is a consortium of Rice University, Texas A&M University, The University of Houston, The University of Texas, Prairie View A&M university, Sam Houston State University, and the Baylor College of Medicine MR Center. This work was also supported by the SSC laboratory.

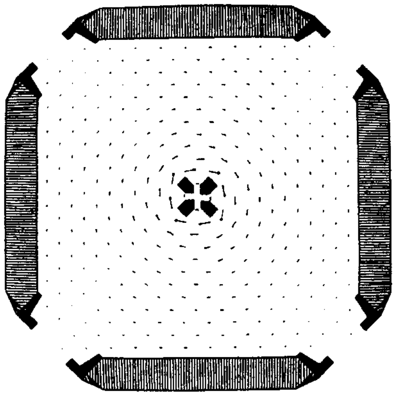

Figure 2. Plot of the magnetic field in the middle of a module. (MAFIA output)

All parts of the structure are bolted together, and as a result, it can be fully disassembled. To make it possible for the vanes to be positioned exactly in place and attached to the square plates, each plate is split diagonally into two halves. The rods are then held in place between these two halves and positioned using dowel pins. To make good rf contacts at the joints, thin annealed copper wires are squeezed in at the contact points between the plates and the sidewalls, and the rods and the plates. However, we need not worry about the quality of the joints between the two halves of the square plates; since they fall on one of the two diagonal symmetry planes which have no currents crossing them.

To design such a structure at a specific frequency, we only need to design a module using the MAFIA code. Since the structure is made of a series of identical modules it will have the same frequency, quality factor, power per unit length, etc., as a single module. Our RFQ structure is made of 10 module. Table 1 lists the dimensions of a module for the 473 MHz structure. It also lists the frequency and Q factor predicted by MAFIA and capacitance per unit length of the vanes calculated by the CAP program, a modification of POSSION for calculating capacitance. Note that the quality factor predicted by MAFIA is not a good prediction since the Q factor also depends on other factors such as small geometrical details, surface quality, and so on, which are not taken into account by the code.

The Cold Model

A cold model consisting of four modules was constructed. In this model the geometry of the vanes is the same as that the RFQ's except that they are shorter and the shapes of the tips of the vanes are different. However, using the CAP program we made sure that the intervane capacitance per unit length is the same in both cases. A resonant frequency of 471.5 MHz was measured for the quadrupole mode. this was less than half a percent away from the design frequency of 473 MHz. Then by slightly modifying the geometry of the back of the vanes, the resonant frequency was changed to 473.1 MHz. The unloaded quality factor for this model was 4400. More importantly, no neighboring mode was seen within 100 MHz of this mode, which confirms our prediction that there is no mode mixing to worry about. Fig 3 shows the reflection coefficient versus the frequency. The sharp absorbtion happens at the resonant frequency 473.1 MHz. The cold model can be fine tuned within about 1 MHz simply by inserting a copper rod into one of its four corners.

TABLE 1

Dimensions of a 473 MHz module

Length of the module(ℓ)	5.48 cm
Width of square plates (W)	18.8 cm
Thickness of the plates (T)	1.27 cm
Intervane capacitance (C_T)	107 pf/m
MAFIA Results:	
Frequency	473 MHz
Q	8500

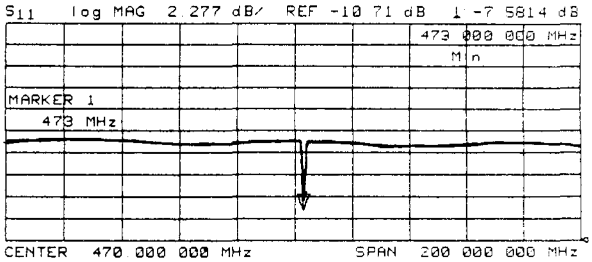

Figure 3. The reflection coefficient vs. frequency for the cold model.

The Beam Dynamics Design

The beam dynamics of the RFQ has been studied using the PARMTEQ program. In this design an effort has been made to keep the length of the RFQ short and the intervane voltage low, so that the total power required is below 100 kW. The input to the RFQ is 10 mA and .7 π mm·mrad (normalized 90%) emittance. The output beam should be about 9 mA with less than 10% emittance growth. Table 2 and figure 4 give the parameters of the RFQ.

The RFQ

The RFQ consists of 10 modules described above. At the low energy end of the RFQ, a small single gap cavity has been added to eliminate any axial electric field at the

TABLE 2

Ions	H^-
Target frequency	473 MHs
Initial energy	30 keV
Final energy	500 keV
Vane length	56.25 cm
Intervane voltage	67 kV
Aperture (r_0)	0.25 cm
The Cold Model:	
Frequency	473.1 MHs
Q	4400
The RFQ:	
Frequency	470.3 MHs
Q	4800
Power	90 kW

beginning of the RFQ. The two opposite corners of the wall between this extra cavity and the first module of the RFQ have been opened wider to let the magnetic field couple the cavity to the first module of the RFQ. The resonant frequency is kept constant by decreasing the length of the first module in the RFQ from 5.48 cm to 4.1 cm.

The coordinates for machining the RFQ vane tips were calculated based on the PARMTEQ results. The transverse radius of the vane tip is 0.188 cm ($0.75 \cdot r_0$) and is kept constant through the RFQ length. The machining of the vanes turned out to be a difficult job and great care was needed for two reasons. The first was to make sure that data points were smooth enough, since after machining, no polishing was allowed. This is because the vanes have to hold high surface electric fields and polishing would embed small particles to the surface and create possible sparking points. The second reason was that machining the vanes was to be done to high tolerances over their full length as required by the beam dynamics. This was successfully done on the MAZAK computerized numerically controlled milling machine. A high speed cobalt tool was used to machine the modulation on the vanes which are made of tellurium copper.

A resonant frequency of 470.3 MHs was measured for the RFQ. This is lower than the design frequency of 473 by about half a percent and will be fixed by tuning. The unloaded Q value is 4800, requiring a structure power of about 90 kW which is within the reach of our 100 kW rf source. Figure 5 shows the reflection coefficient versus the frequency for the RFQ and once again there are no neighboring modes.

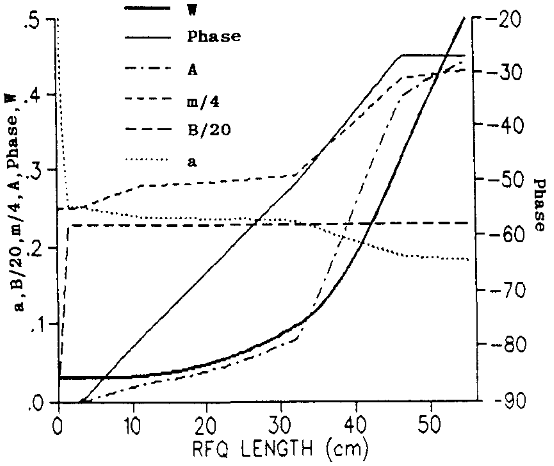

Figure 4. The RFQ parameters vs. RFQ length.

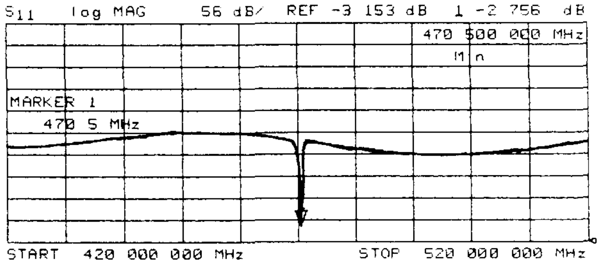

Figure 5. The reflection coefficient vs. frequency for the RFQ.

Conclusion

Thus far the cold model tests of our structure and low rf power measurements of the RFQ have been accomplished and results have had a good match with the calculations. The next step is to do the full power test of the RFQ. Finally, the RFQ will be attached to the ion source and The LEBT system.

References

1. A. Schempp et al., "Zero–Mode–RFQ Development in Frankfurt," in Proceedings of the 1984 Linear Accelerator Conference, 100 (1984).
2. R. Kasimi, "A Four–Rod Cavity RFQ," in Proceedings of the 1988 Linear Accelerator Conference, 140 (1988).
3. R. Kasimi et al., "Study Of A Four–Rod RFQ Structure At 470 MHs," in Proceedings of the 1989 IEEE Particle Accelerator Conference, 990 (1989).
4. R. Klatt et al., "MAFIA – A Three–Dimensional Electromagnetic CAD System for Magnets, RF Structures, and Transient Wake–Field Calculations," in Proceedings of the 1986 Linear Accelerator conference, 276 (1986).