

OPERATION OF A 473 MHZ FOUR-ROD CAVITY RFQ†

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Abstract

We have constructed a new type of four-rod Radio Frequency Quadrupole to operate at 473 MHz. Four-rod structures have not been previously built for such a high frequency. The RFQ is designed to accelerate 10 mA of H<sup>-</sup> ions from 30 keV to 0.5 MeV. The rf measurements and beam test of the RFQ have been performed successfully. Here, we present operational results of the RFQ system including measurements of the beam current, the required rf power, energy, energy spread, and emittance.

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 several advantages such as simplicity of structure and elimination of the dipole modes. 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. We have developed a four-rod type design for these higher frequencies by introducing a small variation to the Frankfurt geometry [2,3]. After designing several simple test models, we set out to make a test RFQ at 473 MHz and to accelerate a 10mA of H<sup>-</sup> ion beam from 30 keV to 500 keV. The cold model tests matched our matched our calculations very well [4]. Next, we built the final structure which was powered by a pulsed klystron [5]. The RFQ was manufactured and beam tested with very good results. This paper will discuss the design of the RFQ briefly, the results of the cold and high power rf tests, and beam test results.

Structure

The structure is made of a series of modules. Figure 1 shows two modules next to each other. Each basic module of length  $\ell$  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 rf current flows back and forth

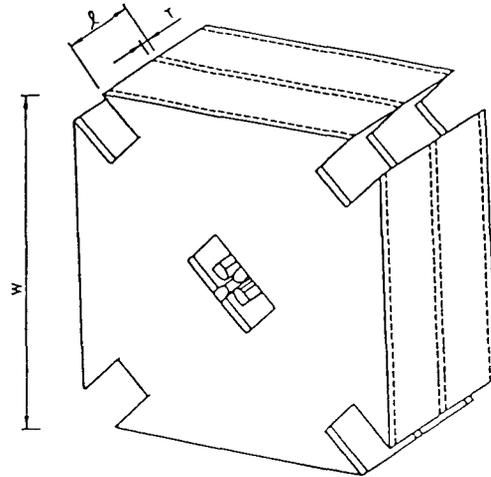


Fig. 1 Two modules of the 473 MHz structure.

Table 1  
 Dimensions of a 473 MHz module

Length of the module ( $\ell$ )	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	

from each rod to its adjacent rods over the inner surface of the modules.

Since the two opposing rods are attached to the same plates at many points through the structure, the unwanted dipole mode, which appears when the two opposing rods oscillate at different voltages, is not a problem. This is an advantage that all the four-rod type structures share over the four-vane types in which the dipole mode mixing can be a serious problem.

Table 1 lists the dimensions of a module for the 473 MHz structure. Our RFQ structure is made of 10 modules. All parts of the structure are bolted together and can be fully disassembled.

Beam Dynamics Design

The beam dynamics of the RFQ has been studied us-

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ing 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 RFQ is designed for a 10 mA input beam. The output beam should be about 9 mA with less than 10% emittance growth. Table 2 and Figure 2 give the parameters of the RFQ.

Table 2  
RFQ Parameters

Ions	H <sup>-</sup>	
Target frequency	473	MHz
Initial energy	30	keV
Final energy	500	keV
Nominal Current	10	mA
$\epsilon_t$ (n,rms)	0.22	$\pi$ mm.mrad
Transmission	95%	
Vane length	56.25	cm
Intervane voltage	67	kV
Aperture ( $r_0$ )	0.25	cm
Structure Power	90	kW

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's length. The machining of the vanes was done on a computer controlled milling machine. A high speed cobalt tool was used to machine the modulation of the tellurium copper vanes.

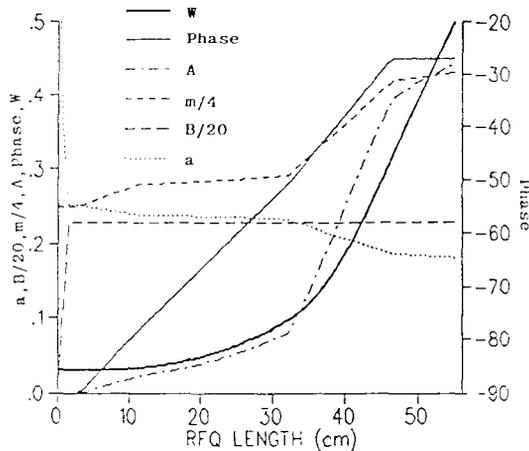


Fig. 2 RFQ parameters vs. RFQ position

RF Test Results

low RF Power Measurements

A resonant frequency of 470.3 MHz was measured for the RFQ. This is lower than the design frequency of 473 MHz by about half a percent and can be corrected by

tuning. The measured unloaded Q value is 5000, requiring a structure power of about 90 kW which is within the reach of our 100 kW rf source. Figure 3 shows the reflection coefficient versus the frequency for the RFQ. No neighboring modes are seen within 100 MHz span of the desired mode, which confirms our prediction that there should be no mode mixing.

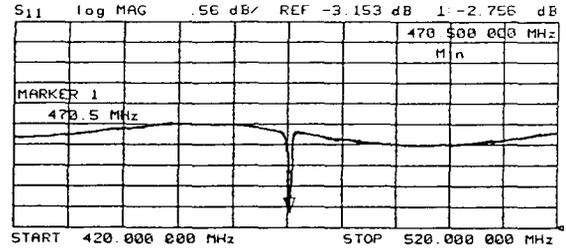


Fig. 3 Reflection coefficient vs. frequency

High RF Power Measurements

We have seen indications of multipactoring between the RFQ vanes at power levels from ~ 200 mW to a few kilowatts. However once getting to higher power levels, we did not see any indications of serious multipactoring anywhere in the cavity. The RFQ was conditioned successfully up to 112 kW with 20 $\mu$ s pulses and 0.1% duty factor [6]. This is well above our 90 kW target. The RFQ is water cooled on three sides and the temperature is monitored and kept constant within one degree celsius.

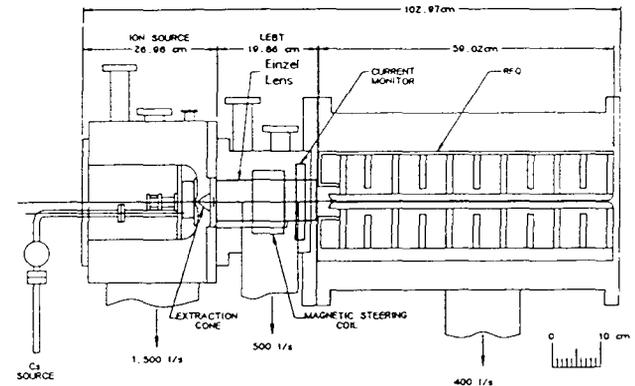


Fig. 4 500 keV accelerator assembly.

Beam Test Results

The beam test was performed using a magnetron H<sup>-</sup> ion source and a single Einzel lens (figure 4). An accelerated beam was observed as soon as the RFQ was powered! The important parameters measured in this test were the transmission factor, the energy spectrum of the beam, the amount of rf power required for operation, and the emittance of the accelerated beam [7].

To obtain the transmission factor, the input and output currents were measured using a current toroid and a Faraday cup, respectively. For an input current of 3.75 mA, an output current of 3.5 mA was measured resulting in a transmission factor of 93%.

A 45° bending magnet was used to analyze the beam's energy spectrum. Figure 5 shows the spectrum of unaccelerated (rf off) and accelerated (rf on) beam. The accelerated beam has a central peak at 478 keV 4.4% away from the design energy of 500 keV. Note that the humps on the sides of the peak are due to secondary electrons which were not fully suppressed. The  $\delta E/E$  is 9.8%, after accounting for measurement errors.

The amount of rf power needed to produce the designed voltage on the four electrodes was measured using the same 45° bending magnet. The magnet was set to measure the intensity of the accelerated beam, while the rf power level was changed. The result is graphed in figure 6 showing a plateau starting about 88 kW. This compares well with our prediction of 90 kW for required rf power.

The beam emittance was measured using an electric-sweep emittance scanner [8]. In this test, however, both the emittance measuring device and the ion source did not perform as well as we expected. The accelerated beam emittance was measured to be 0.7 (norm,90%)  $\pi$  mm.mrad while 0.4  $\pi$  mm.mrad was expected.

Conclusion

The rf and beam tests of the RFQ have been accomplished, and the results are in good agreement with the calculations. This study has proven this new structure as a viable RFQ structure design which can have a host of different applications in a variety of fields.

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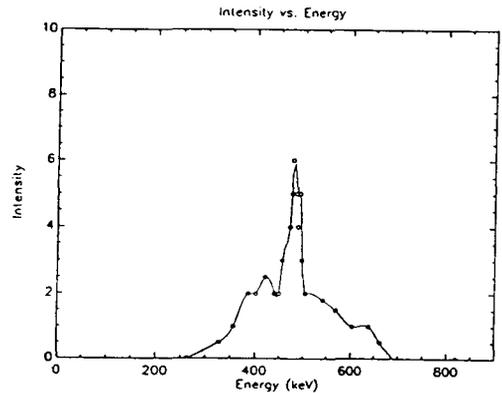
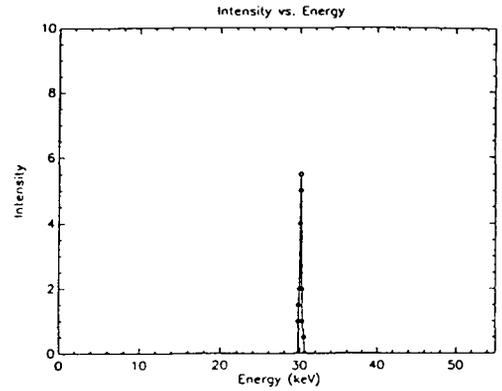


Fig. 5 Energy spectrum rf off (top) and rf on (bottom)

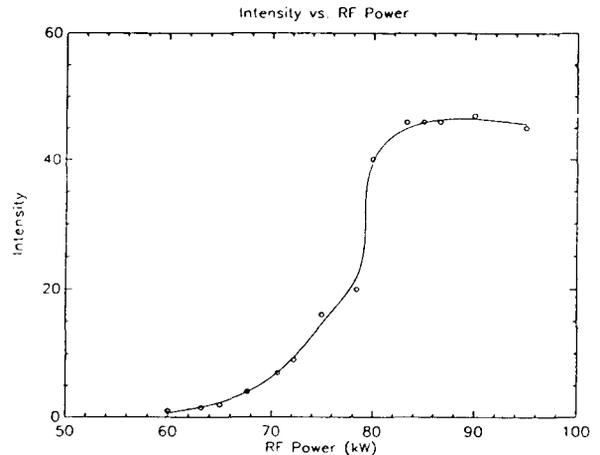


Fig. 6 Intensity of the accelerated beam vs. rf power

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