STATUS OF THE PEFP 3 MEV RFQ DEVELOPMENT*

Y.S.Cho#, B.H.Choi, S.H.Han, J.H.Jang, Y.H.Kim, H.J.Kwon, C.B.Shim

PEFP, KAERI, Korea

Abstract

In the PEFP (Proton Engineering Frontier Project), a 350 MHz, 3 MeV RFQ (Radio Frequency Quadrupole) has been developed and tested. The tuning results showed that the resonant frequency is somewhat higher than 350 MHz and other methods in addition to slug tuners should be used to tune the cavity correctly. To check the cavity characteristics, high power RF test has been done. The required peak RF power of the cavity to consider the beam loading and 75% Q degradation is 535 kW and pulse width, repetition rate for initial test are 50 μs, 0.1 Hz respectively. To solve the problems in PEFP RFQ, the upgrade design of 3 MeV RFQ has been decided. The main concept of this upgrade design is constant vane voltage profile with the same length, compared with the old RFQ. The other parameters such as frequency, energy and current are the same with the previous RFQ. With constant vane voltage profile, fabrication of RFQ can be easier, and with the same mechanical dimension, other parts such as vacuum pumping station can be re-used. In this paper, the test results of the PEFP RFQ, and the design concept of the new RFQ is presented.

INTRODUCTION

The PEFP RFQ has been designed and constructed to accelerate proton beam from 50 keV to 3 MeV. The RFQ is a 324 cm–long, 4-vane type and composed of 4 sections with 36 slug tuners, 8 vacuum pump ports. A coupling plate is used between two segments to stabilize the longitudinal field. The transverse field stabilization is accomplished by dipole stabilization rods. The operation mode of the RFQ is pulse whose maximum pulse width and repetition rate are 2 ms, 120 Hz respectively. The peak RF power which considers the beam loading and 75% Q degradation is 535 kW. The tuning results showed that the resonant frequency of the cavity is somewhat higher than design frequency. Therefore other methods in addition to slug tuners should be used to tune the cavity correctly. To check the overall system including high power RF system, vacuum system, cooling system in addition to cavity characteristics, high power RF test has been done. In order to meet the resonant condition, the RF system was operated in FM mode. The PEFP RFQ is shown in Figure 1 and parameters of RFQ are given in table 1. To solve the problems in PEFP RFQ such as sharp edge and reverse curvature radius at radial matching section in addition to the tuning problem, the new design and fabrication of 3MeV RFQ has been decided [1].

Figure 1. PEFP 3MeV RFQ

Table 1. PEFP 3MeV RFQ Parameters

Particle	Proton
Frequency	350.0 MHz
Input / Output Energy	50 keV / 3.0 MeV
Max. Peak beam current	20.0 mA
Input / Output Emittance	0.2 πmm.mrad
Transmission	95.4 %
Repetition rate	120 Hz
Pulse Width	0.1 – 2 ms
Max. Beam Duty Factor	24 %
Max. Average Beam Current	4.8 mA
Peak Surface field	1.8 Kilpatrick
Length	3.24 m
Peak RF Power	535 kW (75% Q. Calculated)
Field Stabilization	Resonant Coupling Dipole Stabilizer Rods

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Email: choys@ kaeri.re.kr

INITIAL RF POWER TEST

The vacuum system for RFQ consists of two cryopump for cavity, a TMP for each window and beam dump side. The vacuum inside the cavity and window was maintained less than 2E-7 Torr before the test.

The high power RF system for RFQ consists of klystron, circulator, waveguide components, RF window and power coupler and is designed to have the capacity of operating at high duty level. The RF power from the klystron was divided into two legs by magic tee and delivered to RFQ. The TH2089F klystron can be operated up to high duty, and for the test, only the low level input signal to the klystron was pulse modulated without electron beam modulation, that is to keep the constant electron beam power. The circulator can deliver RF power up to 1.3 MW in forward direction and permit up to 1.3 MW reverse power at any phase. The RF window is a planar type and can deliver 900 kW into the load with VSWR less than 1.1. The power coupler is a ridge loaded waveguide type with iris coupling. The holes at the end of the coupling slot were used to match the impedance. In PEFP RFQ, the diameter of the coupling hole was determined as 6 mm for critical coupling [2].

The security box was used to protect the high power RF component and RFQ from RF related problems. All RF related fault signals such as klystron window arc, circulator arc, RF window arc and high reflected power from the RFQ were the input signals of the security box and the output signal from the box was used to interrupt the low level RF signal.

During the RF power test, the resonant frequency changes according to the temperature of the cavity. In PEFP RFQ, the change rate is about –10 kHz/°C. Because the temperature control system of cooling water depends only on the external cooling fan in existing cooling system of PEFP RFQ, it is difficult to regulate the coolant temperature precisely. Therefore it was determined to control the driving frequency against the resonant frequency change according to the temperature of the cavity cooling water, that is to operate the RF system in FM mode [3]. For the initial RF power test, the RFQ was driven from low power level at 352.1 MHz, 50 µs, and 0.1 Hz. The RF parameters such as the forward power, cavity power, reflected power from RFQ, and power toward klystron were monitored. Until now, the RF power with the above pulse parameters was delivered into the RFQ stably up to 250 kW. The RF signal at this power level was shown in Figure 2. The upper part in Figure 2 is the forward power to the klystron, and the lower part RFQ pick up signal. At this power level in Figure 2, continuous proton beam was injected into the RFQ from the ion source whose energy was 50 kV. To avoid the damage of the RFQ resulted from the focused proton beam, the beam matching or focusing using LEBT was not used but the beam was rather spread into large area. The pulsed beam current from the Faraday cup at the location of 70 cm downstream from the RFQ exit was shown in Figure 3. The beam current was about 2 µA. From the calculation,

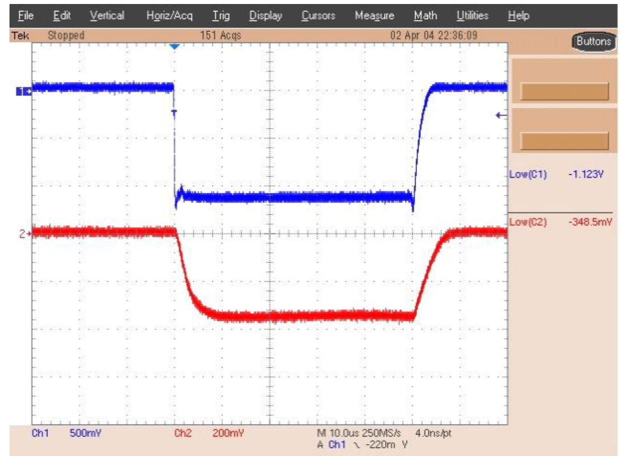

Figure 2. RF signal (10 µs/div.)

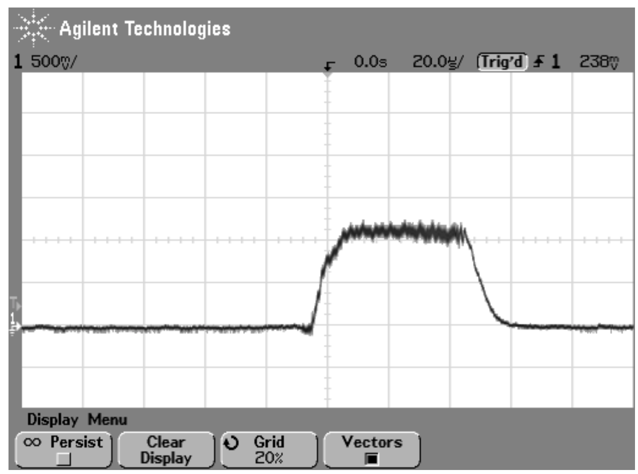

Figure 3. Pulsed beam signal from Faraday cup (20 µs/div., 1 µA/div.)

the voltage factor at the operating RF power level was about 73% and the estimated transmission rate was above 90%.

BEAM PROFILE MEASUREMENTS

Non-destructive CCD beam profile monitor (BPM) using residual gas fluorescence is developed for the RFQ beam matching at the LEBT. Residual gas molecules in the beam pipe interact with the passing proton beam and then the neutral or ionized residual gas is promoted to excited state. The CCD camera can collect the photons emitted by the electron transitions of the excited molecules, leading to measurement of the beam profile. Figure 4 shows the image and beam profile of the proton beam intensity (2 mA, 20 keV) in single shot mode over 3 sec at a background gas pressure of 4 x 10^{-5} Torr. We estimate the beam size to be less than 2.2 mm FWHM from Gaussian fits of the beam profile measurements.

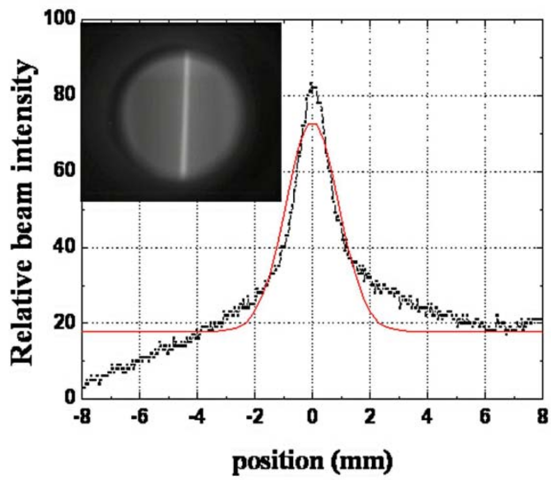

Figure 4. Beam profile image of a 20 keV proton beam.

BEAM ENERGY MONITOR

In order to measure the proton beam energy of the PEFP RFQ, a gas scattering energy monitor has been constructed (Fig. 5). The energy monitor is comprised of gas scattering chamber, collimator, and surface barrier detector. The operating principle of the apparatus is to use gas scattering and collimator. Beam going through the first collimator is spread out by multiple Coulomb scattering with scatter gas and is attenuated through the second collimator. The reduced beam flux allows the silicon surface barrier detector to be utilized. A gas of high atomic number such as Xe is to be used to increase the scattering angle.

Figure 5. Energy monitor to measure the beam energy of the RFQ.

NEW RFQ DESIGN

The new RFQ has been designed on the principle that (1) the geometry is similar to the existing RFQ, (2) the vane voltage is constant, (3) the aperture radius is slowly increasing after the gentle buncher, and (4) the transition cell [4] is adopted at the end of the RFQ. The third principle implies that the zero current phase advance per unit length becomes larger in the transverse direction. Then it's possible to achieve the current-independent beam matching between the RFQ and DTL by adjusting the first four quadrupole magnets in the DTL. The transition cell makes the length of the fringe field region to be a free parameter. The suitable output beam of the RFQ for matching can be obtained by changing the length [5].

CONCLUSION

To check the overall RFQ system including cavity, high power RF system, vacuum system, and cooling system, RF test has been carried out for the PEFP 3 MeV RFQ. The operating parameters are 50 μs, 0.1 Hz and until now the RF power was delivered into the RFQ up to 250 kW without any problems. At this power level, modulated proton beam was measured at the exit of the RFQ.

The CCD BPM based on the residual gas luminescence has been constructed and a preliminary test with a 20 keV, 2 mA proton beam was performed under a residual gas pressure of 4 x 10^{-5} Torr. The gas scattering energy monitor has been fabricated to measure the proton energy at the exit of the RFQ.

The beam dynamics design of the new RFQ was done and engineering design is being carried out.

ACKNOWLEDGMENT

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