CHARACTERISTICS OF THE PEFP 3 MEV RFQ*

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Abstract

A four-vane type 3 MeV, 350 MHz RFQ (Radiofrequency Quadrupole) has been developed as a front-end part of PEFP (Proton Engineering Frontier Project) 100 MeV accelerator. After the completion of the field tuning and high power conditioning at reduced duty, the initial operation of the RFQ with beam was carried out. During initial test period, several parameters related with the RF and beam were measured to characterize the performance of the RFQ. Based on these measurements, several suggestions for further improvement were proposed. In this paper, the initial test results are discussed and the suggestions for the system improvement are summarized.

INTRODUCTION

A 100 MeV proton linear accelerator has been developed at PEFP and 20 MeV accelerator was already fabricated and tested [1]. The 50 keV ion source, LEBT (Low Energy Beam Transport) and 3 MeV RFQ constitute a front-end part of the 20 MeV accelerator. The ion source is a Duoplasmatron type and operated in pulse mode by switching the beam extraction power supply. The LEBT consists of two solenoid magnets for focusing and two dipole magnets for steering. A 3 MeV, 350 MHz RFQ is a four vane type and consists of four sections. A resonant coupling plate and dipole stabilizer rods are used for longitudinal and transverse field stabilization [2][3]. The main design parameters of the RFQ are summarized in Table 1. After the completion of the fabrication, low power field tuning, high power conditioning and beam tests have been performed successively.

Table 1. PEFP 3 MeV RFQ Design Parameters

Frequency	350 MHz
Input / Output energy	50 keV / 3 MeV
Input / Output current	22 mA / 20 mA
Vane voltage	85 kV (constant)
RF Power (80% Q)	460 kW
Input emittance	0.02 cm-mrad (normalized rms)
Output emittance	0.022 cm-mrad 0.112 deg-MeV
Transmission rate	98.3 %
Duty	24 % (Max.)
Repetition rate	120 Hz (Max.)
Total length	325 cm

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LOW POWER FIELD TUNING

The requirements for the field tuning are that the quadrupole field profile is within 2 % of the design value and the dipole field profile is less than 5 % of the quadrupole field. To accomplish these requirements, the tuning steps were divided into three stages. 1) vane adjustment before brazing of each section, 2) one segment (consists of two sections) tuning, 3) the whole RFQ tuning including dipole rods and coupling plate. The field measurement was performed using bead perturbation method in magnetic field region. A 9.53mm diameter aluminium hollow ball was used as a bead. The total number of tuners was 52 ea. Four dipole rods were used at both ends of the end plate but no dipole rods were at coupling plate. The coupling plate thickness was 16 mm. The final field profiles after the completion of the low power field tuning are shown in Figure 1 and Figure 2 respectively. As shown in the Figures, the quadrupole field is within 2 % of the design field profile and two dipole fields are less than 2 % of the quadrupole field, which satisfy the requirements.

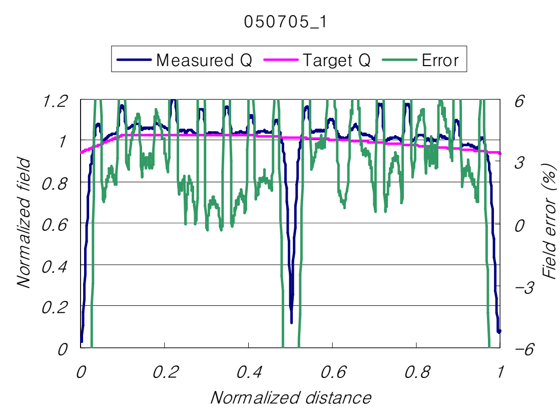

Figure 1: Quadrupole field profile along the RFQ.

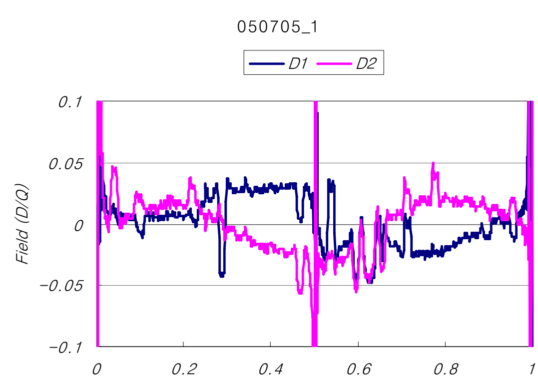

Figure 2: Dipole field profile along the RFQ.

HIGH POWER CONDITIONING

The fabricated RFQ was installed at KAERI test stand as shown in Figure 3.

A 1 MW, 350 MHz klystron (TH2089F, THALES) is installed to drive the RFQ. The RF power from the klystron is divided into two ways into the RFQ because of the window power limiting. Two planar type windows (THALES) were used for vacuum barrier and two ridge loaded waveguide type with iris coupling for input couplers.

Two cryo pumps were used as vacuum pump for RFQ cavity and a TMP for each window. The vacuum level of the RFQ cavity is better than 2E-7 torr and window better than 1E-7 torr.

The 3 MeV RFQ is installed at KAERI test stand, where the ambient conditions are not stabilized. Therefore the RFQ needs temperature stabilization mechanism. The 1 kW heater and heat shields were installed around the RFQ cavity. The heater was controlled by PID mechanism of the SCR power unit. By using this method, the frequency could be stabilized within ± 1 kHz.

The unloaded Q was measured using forward and reflected RF power profile. And the measured value was 8,500 which correspond to about 80 % of the calculation.

The RF parameters for initial test were 350 MHz with 50μs pulse width, 5 Hz repetition rate. Up to 80 kW forward power level, the electron loading phenomena at the power coupler was observed. In the forward power level from 80 kW to 270 kW, there were no electron loading and typical RF pulse profile could be observed. From the forward power level of 270 kW, the electron loading which increased the reflected power and also vacuum level at window was observed again. From this power level, the RF power was increased step by step after the extinction of the electron loading, and it took about 8 hours to increase the forward power level up to 450 kW without electron loading which corresponded to 1.8 Kilpatrick inside the cavity. After the initial RF test, the pulse width was increased step by step up to 100 μs, where stable RF pulse without electron loading could be obtained as shown in Figure 4.

Figure 3 : PEFP 3 MeV RFQ at KAERI test stand.

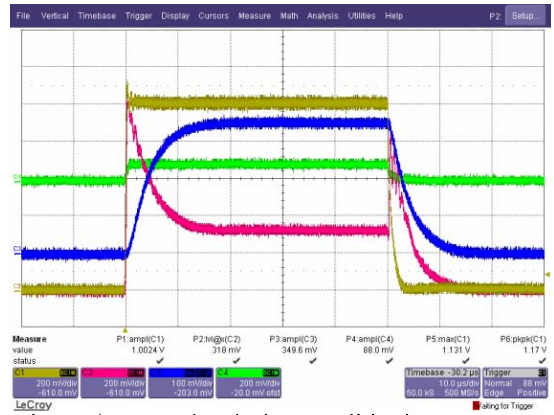

Figure 4 : RF pulse during conditioning
(Ch1 : forward, Ch2 : reflect, Ch3 : cavity,
Ch4 : klystron reflect, horizontal : 20 μs/div.)

BEAM TEST

The maximum operation duty of RFQ is limited by the temperature stabilization heater power and radiation safety at KAERI test facility. Therefore, a beam test was carried out to check the overall system performance at low average power level.

A proton beam from ion source was chopped using semiconductor switches at high voltage power supply. The pulse width of proton beam was 1 ms with 0.1 Hz repetition rate.

A current transformer developed by Bergoz was installed at the exit of the RFQ to measure the beam current. The current transformer is tuned to the fundamental beam frequency, which is 350 MHz and can catch the bunched beam signal component of 350 MHz. The sensitivity of the current transformer is 2.5V/A. Because the peak beam current would range from a few tens μA to a few mA during initial beam test, it is difficult to directly measure the signal from the current transformer. Therefore two stage RF amplifiers were installed.

The beam transmission ratio through the RFQ was measured to set the RF operating point. The output beam current was measured as a function of the input RF power with the assumption that the input beam current was constant during test. The peak beam current during test was about 1 mA and the typical beam signal from the current transformer is shown in Figure 5. The solenoids and dipole magnets in LEBT were adjusted by the RFQ output current level and current shape. The measured beam current and PARMTEQ simulation result are shown in Figure 6. As shown in the Figure, there are differences between the total beam current and accelerated beam current from simulation, which is the typical characteristics of the RFQ. In the test, the current transformer tuned to 350 MHz can act like a filter which pick up the bunched beam signal, therefore the current transformer picked up the accelerated beam signal. From the test results, the operating point of the RF amplitude could be determined, which was about 10 % higher than the designed value.

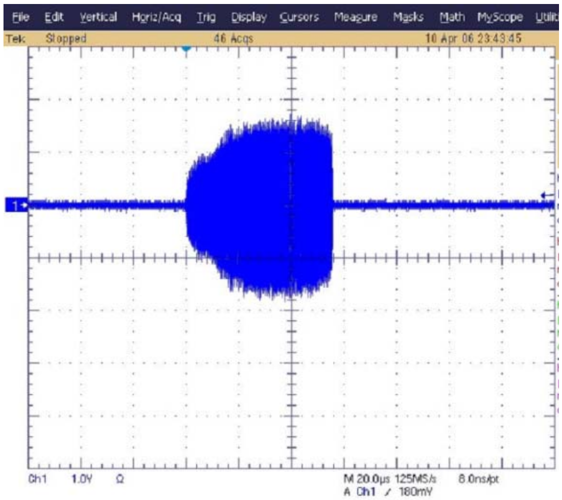

Figure 5 : RFQ output beam signal (horizontal : 20 µs/div., vertical : 500 µA/div.).

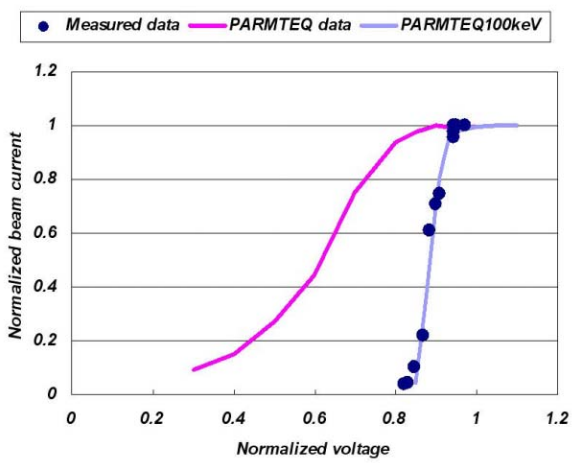

Figure 6 : RFQ output current depending on RF field (Red line : total beam current, Blue line : accelerated beam current, Dot : measured beam current)

DISCUSSION

The PEFP 3 MeV RFQ uses a resonant control cooling schemes to adjust the resonance frequency. We are going to install a resonant control cooling skid for RFQ in new site. Instead, temporary frequency stabilization method using heater and heat shield was used in KAERI test facility, which showed enough stabilization effect.

There is no beam diagnostic device in front of the RFQ. We are going to install a current transformer at the low energy side to measure the input beam current and electron trap to remove the electrons from entering the RFQ. After that, we can understand the performance of the front-end system including ion source, LEBT and RFQ more deeply.

CONCLUSION

The fabricated PEFP 3 MeV, 350 MHz RFQ was installed at KAERI test stand. A low power field tuning was completed. The RFQ was high power conditioned up to the design power level at reduced duty factor. The beam test was performed, and the RF operating point could be determined from the output current characteristics depending on the RF amplitude. Up to now, preliminary performance test was completed. A current transformer and electron trap will be installed in front of the RFQ to understand the performance of the PEFP front-end system more deeply.

REFERENCES

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