PERFORMANCE OF A 13MHZ CAVITY FOR AN RF IMPLANTER AT PEFP*

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Abstract

A 13 MHz - normal conducting cavity for an rf implanter has been successfully developed at PEFP (Proton Engineering Frontier Project). It consists of an inductive coil, accelerating electrodes and a ground electrode for the inductor. Quality factor of 2074 and critical coupling were achieved at resonant frequency of 12.658MHz. Rf power of 1kW was forwarded to the cavity without any spark in the cavity. Beam test was then carried out with a 27keV helium beam generated from a Duoplasmatron ion source. The results showed that the helium beam was accelerated to final energy of 117 keV with energy spread of 1%. Detail experiments and results are addressed in this presentation.

INTRODUCTION

In the conventional ion implanters, ions are accelerated by a constant electric field. Such machines occupy a large space and need to be concerned with high voltage insulation and safety issues. An rf implanter is therefore preferable in some cases. Glavish introduced a resonator which consists of a single coil and electrode operating at 13.56MHz [1] for an rf implanter. Developed from this model, in this paper, we present a new design concept of the cavity. The main different from previous work is coupling an additional coil to the original one which reduces the resonant frequency and increases the quality factor (Table 1). Detailed design concept, rf properties measurement and beam test are addressed in this paper.

Table 1: Cavity Parameters

Parameter	This work	Glavish's work
Operation frequency (MHz)	13	13.56
Gap length (mm)	6	-
Peak field (Kil.)	1.12	-
Cavity inner diameter (mm)	400	-
Effective shunt impedance (MOhm)	15	7.5
RF power (kW)	1	3
Accelerating voltage (KV)	125	160

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MEASUREMENT OF THE RF PROPERTIES

We measured the resonance frequency spectrum of the cavity with a Network Analyzer. The frequency spectrum at the fundamental mode is shown in Fig. 1. The resonant frequency of 12.92MHz was achieved which is somewhat lower than designed value. This might due to the error in fabrication as well as the misalignment in installation.

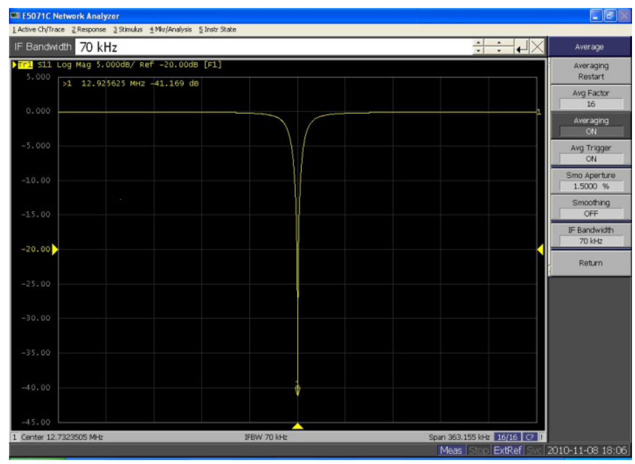

Figure 1: Frequency spectrum.

RF signal was forwarded into a cavity by a loop coupler connected to the central conductor of a type N connector. The coupling coefficient is adjusted by varying the coupling loop diameter. The measurements of coupling coefficient and quality factor are summarized in Table 2. The measured unloaded quality factor is about 80% of simulation value which is generally acceptable. Critical coupling was obtained with a 6.36cm diameter loop antenna which agrees well with the analytical model.

Table 2: Quality Factor and Coupling Coefficient

Loop diameter (cm)	Coupling coefficient	Loaded quality factor	Unloaded quality factor	Simulation
4.5	0.176	1757	2066	2500
5.4	0.404	1505	2113	2500
6.4	1.017	992	2074	2500
8.3	2.900	619	2054	2500

The bead pull method was used to measure the field distribution in the cavity. The experimental setup is given in Fig. 2. A 10 mm diameter aluminum bead was pulled through the cavity by using a step motor equipped with a controller. The phase shift was detected by using a network analyzer (Agilent E5071C). The step motor speed was 7.5 mm/sec and the measurement time was 38.6 seconds. The field profile is given in Fig. 8. The field flatness is 6.5%, which satisfies the control requirement for the field in the cavity (<8%). This quite large field flatness might be caused by the misalignment of the electrodes during the installation process.

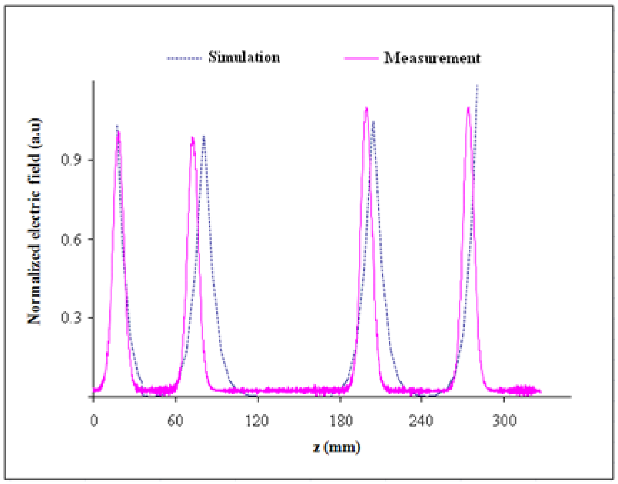

Figure 2: Field distribution in the cavity

ACCELERATION OF HELIUM BEAM

Experiment Setup

Experiment set up is shown in Fig.3. 27 keV $^4He^+$ ions were generated from a duoplasmatron ion source. They were then focused by a compact triplet [2] with the focusing strength of 1.12 T/m. The beam was accelerated by the cavity, described above and bended by a 90 degree bending magnet to diagnostic chamber. The bending radius of this magnet is 370mm. RF system includes a 13.56 MHz FET plasma generator (YSR 25MH) and a phase locked loop (PLL) circuit which was used to make the frequency of the rf generator follows the frequency of the cavity. Beam current was detected by a Faraday cup attached into the diagnostic chamber, amplified by an amplifier (Stanford Research SR 570) and recorded by an oscilloscope (Tektronix TDS5054B).

The forward RF power was increased gradually while the reflected power and the vacuum level were being monitored. At such a low forward RF power, the reflection was large especially at the RF power coupler and this large reflection might be due to the multipacting. The large reflection in the RF power coupler could be identified by a sharp increase in vacuum level. When the forward power was increased to the level of about 0.8 kW for the cavity, this large reflection was drastically diminished and the field in the cavity recovers the normal wave form.

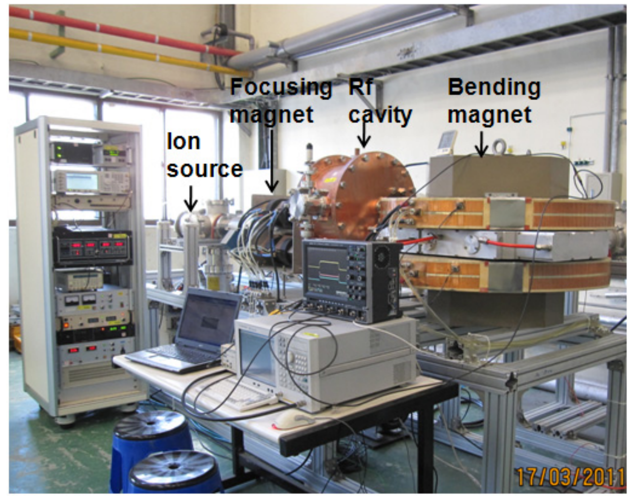

Figure 3: Experiment setup.

From this point the forward RF power can be increased to the design value of 1 kW, without spark in the cavity. Then, the pulse duration and the repetition rate were increased gradually to 1 ms and 1 Hz respectively. Beam current of 2uA, which is within safety limit at the very beginning stage was achieved. The waveforms of the forward RF power, and beam current for the case of 1ms and 1 Hz are shown in Fig. 4a. Magnetic rigidity of the beam was calculated to be 0.098T-m. It confirms the beam energy is 117keV.

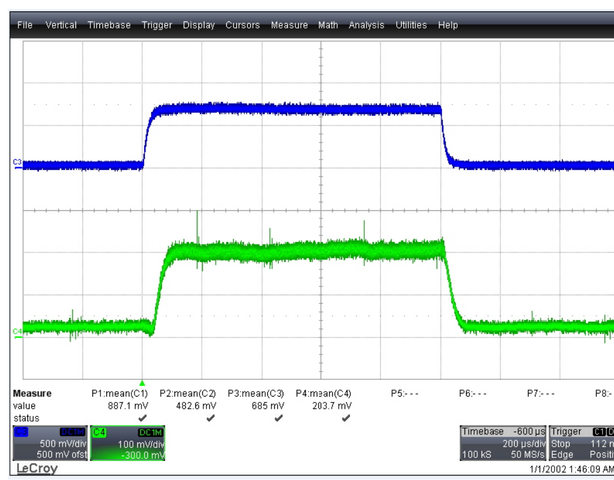

Figure 4a: Forward power (C3) and beam current (C4) signals.

Bunched beam signals in time and frequency domain are shown in Fig.4b and Fig. 4c, respectively. The signal was presented in frequency domain by Fourier transform. The frequency of bunched beam signal is 12.68MHz, which is slightly shifted from driving frequency. It can be explained due to the noise of the signal.

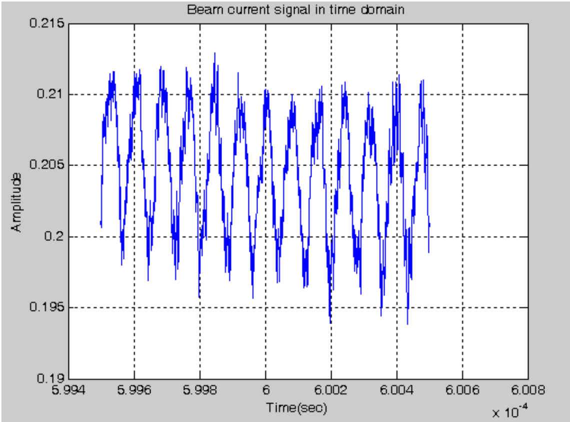

Figure 4b: Beam current signal in time domain.

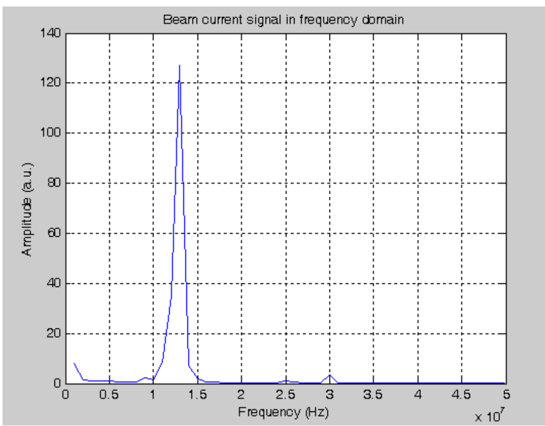

Figure 4c: Beam current signal in frequency domain.

The beam profile was measured with a wire scanner placed at the beam waist which is 400mm far away from the exit of the bending magnet. At the beam waist where betatron reaches minimum, the beam size is given by:

$$r_{rms} = D\frac{dp}{p} \quad (1)$$

where r is the rms beam radius, D is dispersion and dp/p is the momentum spread. With a bending magnet with bending angle and radius of 90^0 and 370 mm, respectively, dispersion at the beam waist is calculated to be 770mm. The beam profile was then fitted with a Gaussian distribution to obtain the rms beam radius (Fig. 5).

We measured the beam profile with different ion source arc current of 0.44A, 0.47A and 0.51A, which are summarized in Table 2. The energy spread increased when increasing arc current and was determined to be <1%.

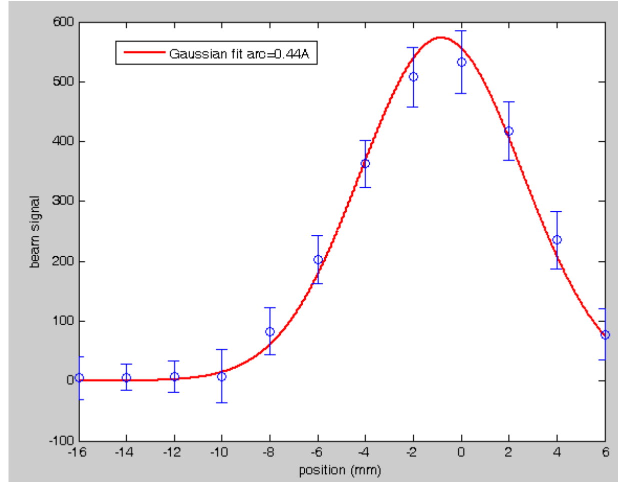

Figure. 5: Beam profile measurement.

Table 2: Measurement of the Energy Spread

Arc current (A)	**0.44**	**0.47**	**0.51**
Rms beam radius r (mm)	3.392 ±0.761	3.517 ±0.452	3.788 ±0.405
Dispersion function at the beam waist D (mm)	770.000 ±1.500	770.000 ±1.500	770.000 ±1.500
Energy spread (%)	0.880	0.912	0.984
Uncertainty (%)	0.098	0.059	0.053

CONCLUSION

A cavity with new design concept which has low power dissipation has successfully been designed, fabricated and tested. The fundamental resonant frequency of this cavity of 12.92 MHz was obtained. Unloaded quality factor was measured to be 2074, agreeing well with simulation result. Critical coupling was achieved with a 6.36cm diameter loop coupling. A helium beam was successfully accelerated by this cavity at final energy of 117 keV with beam current of 2uA at 1Hz of repetition rate and pulse width of 1ms and low rf power of 1.2 kW. The energy spread was determined to be <1%. Further test with the cavity as well as design and commissioning of multi-cavities for high energy implanter will be done in near future.

REFERENCES

[1] H.F. Glavish, D. Bernhardt, P.Boisseau, B.Libby, G.Simcox, A.S.Senholm, Nucl. Instr. and Meth. in Phys. Res. B 21 (1987) 264-269
[2] Y.S Cho, H.S Kim and H.J Kwon, Rev. Sci. Ins. 79, 02B715 (2008).