ACCELERATION TEST OF TWO-BEAM TYPE IH-RFQ LINAC

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Abstract

In order to accelerate high intensity heavy ions using RFQ (Radio Frequency Quadrupole) linac, it is necessary to suppress the coulomb repulsive force (space charge effect) between these particles and avoid the beam loss as much as possible. A solution for suppressing the space charge effect has been proposed that a RFQ cavity has several beam channels and accelerates several beams in one cavity.

Therefore, we have studied a multi-beam type RFQ with IH (Interdigital H) cavity that is power-efficient structure in low energy beam acceleration. We manufactured a two-beam type IH-RFQ linac as a prototype of the multi-beam type. As a result of the beam acceleration test of the linac for carbon beams, it had successfully to accelerate from 5 keV/u to 60 keV/u and about 108 mA (2×54 mA/channel) in the output current .

INTRODUCTION

When a RFQ linac accelerates ion beams, the current limit that can be accelerated by the linac is proportional to the beam velocity. Then, it is difficult to generate more than 10 mA heavy ions from the linac in low energy region.

As a solution for this difficulty, an idea has been proposed to divide a single, high intensity heavy ion beam into several beams, and integrate these beams into a single high intensity beam with higher energy. Toward this end, an accelerator technology for heavy ion inertial confinement fusion drivers has been studied [1]. In this case, a beam is accelerated in a cavity conventionally. Therefore, if several beams can be accelerated in a cavity, this method would be better than the existing systems in terms of operational cost saving, construction cost saving and space saving.

Consequently, a multi-beam type RFQ linac, which has several beam channels in one cavity, has been proposed. Frankfurt University proposed a multi-beam type 4-rod RFQ linac that adopted a π-0 type resonant cavity and succeeded in proofing the principle [2]. GSI also proposed a multi-beam type RFQ linac that adopted an IH type resonant cavity, which is high power-efficient structure in low energy beam acceleration [3]. However, this multi-beam type IH-RFQ linac apparatus has yet to be manufactured.

Therefore, we manufactured a two-beam type IH-RFQ linac system as a prototype of the multi-beam type IH-RFQ and conducted the beam acceleration test.

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DESIGN AND PARAMETERS

A photo of the two-beam type IH-RFQ cavity is shown in Fig. 1, which consists of two sets of quadrupole electrodes. The RF electromagnetic field is stimulated by the TE_{111} mode in this IH cavity. The RFQ electric field is generated by four rods installed in each of the stems taking the polarity into consideration.

The cavity was made by stainless steel and coated by copper about 50 μm thick. The quadrupole electrodes and the supporting stems were made by oxygen free copper. The outer wall of the cavity has cooling jacket, and the inside of the supporting stems and that of the quadrupole electrodes has cooling channels of 4 mm in diameter.

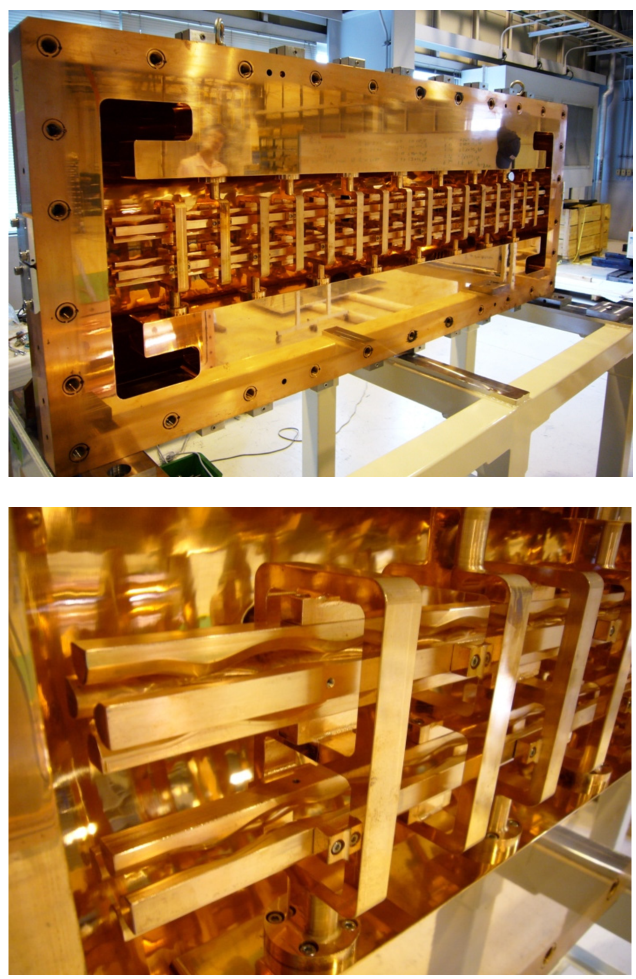

Figure 1: A photo of the two-beam type IH-RFQ linac.

Main parameters of the two-beam type IH-RFQ linac are shown in Table 1. The computer code RFQUICK was used to generate the cell parameters for the PARMTEQM calculation [4]. The RFQUICK is suitable for the design of RFQ linacs whose output beam currents exceed 10 mA. The computer code PARMTEQM was used to simulate the beam dynamics in the RFQ. The electromagnetic simulation software MWS (Micro Wave Studio) was used to calculate the resonance frequency, the Q value and the wall loss of the cavity.

The accelerated particles were set to q/A≥1/6, and C^{2+} beams were accelerated in the test of this linac. The resonance frequency in this cavity is 46 MHz in calculated value. Taking into consideration the maximum output of the RF power source, the wall loss is saved less than about 80 kW including beam loading. A Kilpatrick factor of the maximum field at inter-rod is 1.8 which is the ratio of electric field to the Kilpatrick criterion.

Table 1: Main parameters of the two-beam type IH-RFQ

Charge to mass ratio (q/A)	1/6
Input-Output energy (keV/u)	5→60
Resonance frequency (calculated by MWS) (MHz)	46
Q value (calculated value by MWS)	7500
Wall loss (at normalized inter-rod voltage, 60% Q) (kW)	42
Beam loading (kW)	34
Total power (kW)	76
Average bore radius, r_0 (cm)	0.76
Cavature radious of rod-tip (cm)	0.57
Focusing strength, B	8.754
Defocusing strength (at exit of the gentle buncher section), $\|\Delta\|$	0.216
Synchronous phase, ϕ_s (degree)	-90 → -30
Rod length (cm)	148.12
Total number of cells	104
Cavity length (cm)	150
Cavity diameter (cm)	49.2
Maximum field at inter-rod (Kilpatrick)	1.8

BEAM ACCELERATION TEST

Injection System

We adopted and manufactured a laser ion source with DPIS (Direct Plasma Injection Scheme) for an injection system of the two-beam type IH-RFQ linac (Fig. 2) [5]. After a beam splitter evenly divides a laser beam, mirrors guide each beam to a carbon target on each beam channel. The angle of incidence at the target surface is 30 degree.

The maximum energy per shot of the neodymium-doped yttrium aluminum garnet laser for this test is 1.2 J (0.6 J/channel). The laser beams are focused using plano-convex lenses (focal length 750 mm). The charge state of carbon ion beams outputted from the ion source is controlled by means of changing the output power of the laser and the position of the lenses. As a result of the beam generation test, this ion source generated C^{2+} beam of about 60 mA/channel.

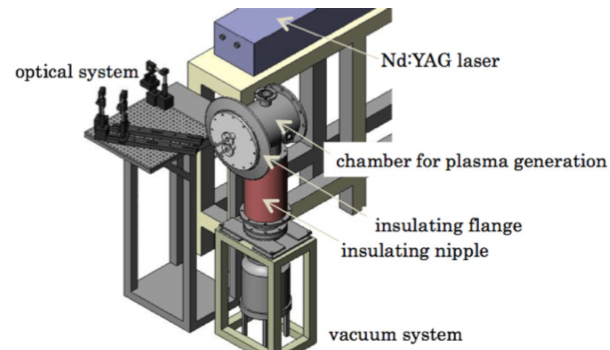

Figure 2: A schematic drawing of the two-beam type laser ion source with DPIS.

Test System

We developed the acceleration test system by connecting the two-beam type IH-RFQ linac and the laser ion source. The pulse rate, the pulse width and the duty factor of the RF were 1 Hz, 1 ms and 0.1% respectively in this test. The background pressure was approximately 8×10^{-5} Pa along the system.

A layout of the accelerator system to analyze the charge state of the accelerated carbon beams is shown in Fig. 3. An ESA (Electro Static Analyzer) placed 2062 mm downstream from the target surface analyze the charge state. A FC (Faraday Cup, opening size 24 mm in diameter) placed 2352 mm downstream from the target surface measures the analyzed electric current. When we measured the total beam current, the other FC (opening size 26 mm in diameter) was used.

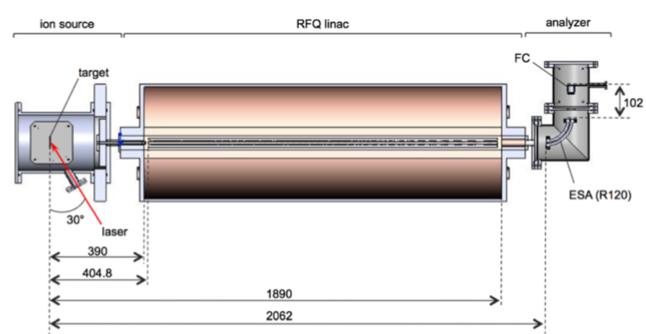

Figure 3: A layout of acceleration test for two-beam type IH-RFQ

Commissioning

We measured a reproducibility of the output beams from the two-beam type IH-RFQ linac. Current waveforms of the output beams in channel 1 are shown in Fig. 4. The variations at the peak current are about 4.8 % in channel 1 and about 5 % in channel 2.

Compared to the output beam waveforms from each beam channel, the pulse forms are in almost-totally step with each other (Fig. 5). The differential of the peak current between each channel is about 0.5 %, and the beam pulse widths are about 4.5 μs in channel 1 and about 4.9 μs in channel2.

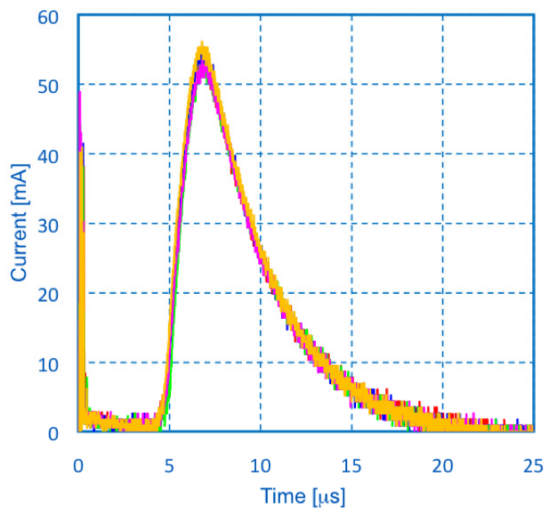

Figure 4: Current waveforms outputted from beam channel 1 in the superposition of 5 laser shots.

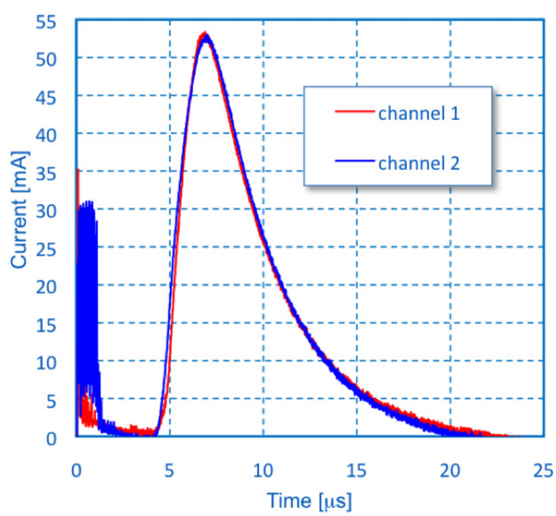

Figure 5: Output beam's waveforms from each channel. This data are averaged over 8 laser shots.

Then, we estimated a ratio of the charge state contained the beam by means of analyzing the accelerated beam using the ESA. The analyzed current are shown in Fig. 6 when the analyzer voltages are 3 kV for no accelerated C^{2+}, 9 kV for C^{4+} of 60 keV/u, 13 kV for C^{3+} of 60 keV/u and 18 kV for C^{2+} of 60 keV/u. Table 2 shows the result of this beam commissioning.

The beam energy is from 5 to 60 keV/u same as the design value. When the input RF power to the cavity is 76 kW, the total output current is about 108 mA (2×54 mA/channel). However, we could not input more power because of a discharge in the cavity.

Summary and Future Plan

We have manufactured a two-beam type IH-RFQ linac and a laser ion source for high intensity ion beam

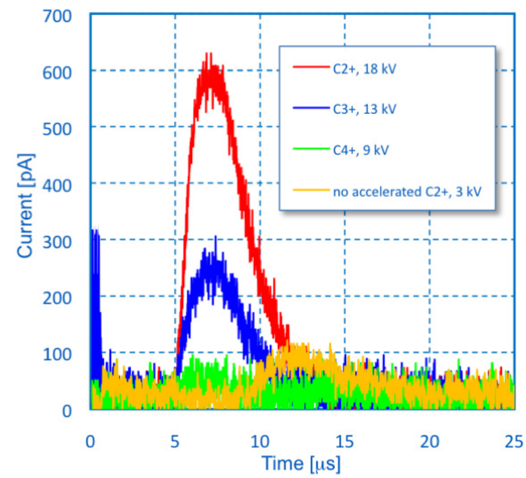

Figure 6: Pulse structure of analyzed beam from the linac.

Table 2: Summary of the beam commissioning in the two-beam type IH-RFQ linac.

Resonance frequency (Hz)	47	
Q value	5900	
R_s (kΩm)	168	
Power density of laser on target surface (W/cm^2)	7.9×10^8	
Input-output energy (keV/u)	5→60	5→60
Input-output current (mA/channel, total)	172→45	172→54
(mA/channel, C^{2+})	61→30	61→36
(mA/channel, C^{3+})	55→12	55→15
(mA/channel, C^{4+})	37→3	37→3
RF power (kW)	65	76
Kilpatrick factor without beam loading	2.5	2.7

acceleration in low energy region. As a result of the test, it had successfully to proof the principle of the multi-beam type IH-RFQ linac.

We could not report because of the space limitation on this paper, however a coherency between two-beam in each channel, which might come from imbalance of the beam loading, have been observed. This coherency becomes a problem for repeatability of the output beam when the difference of the beam current in each channel is bigger than about 5 %. Therefore, we plan to study the mechanism of this multi-beam coherency.

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