IRON BEAM ACCELERATION WITH DPIS*

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Abstract

We commissioned an RFQ with a new set of vanes which is for accelerating q/A > 1/7.2 ions. RF power was successfully fed and beam commissioning test was done by using high charge state iron beam supplied by a laser ion source. The obtained current reached 4.3 mA at the peak. Silver beam, design particle, test using solenoid confinement with direct plasma injection scheme will be carried on soon.

BACKGROUND

In 2004, we commissioned a 4 vane RFQ in NIRS, Chiba in Japan. The RFQ was constructed by IAP of Frankfurt University and was designed to accommodate high current carbon beam from a laser ion source using direct plasma injection scheme (DPIS). We could demonstrate very high current heavy ion beam acceleration with the DPIS and the measured current after the RFQ reached more than 60 mA of carbon beam[1]. However, due to the radiation safety limitation in NIRS, output beam energy of the RFQ was restricted to be below 100 keV/u. The entire cavity length was 2.0 m and the beam energy reached the energy limitation at 1.42 m point from injection side. So, in the rest of the section, the vanes had no modulation. By passing through under the transversely confinement RF field without acceleration buckets, the beams were completely de-bunched. To verify the feasibility of the DPIS, this RFQ had worked great, however, it was difficult to examine the beam qualities, since the output energy was too low to transport a high current beam and the transverse emittance of de-bunched beam was affected by the RF cycle.

In 2005, we started to design new replacement vanes. Based on experimentally obtained performances of a laser ion source using a 2.3 J Nd-YAG laser, silver 15+ ion was selected as the design particle[2]. An assembly of the new vanes with supporting stems and a base plate (without outer vessel) was fabricated in 2006 again by IAP.

In 2006, the RFQ and entire experimental equipment was moved from RIKEN in Japan to BNL in USA. In BNL, the study was continued mainly using the old vanes with un-modulated section[3]. Due to a bureaucratic reason, the vane assembly was sent back to Japan after we moved to BNL. However, during the shipment, it was heavily damaged.

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A photo taken in Japan is shown in Fig. 1. The assembly was sent to Frankfurt directly from Japan and was straightened and aligned again. The repaired new vanes were installed in 2010 and the commissioning was done in 2011 in BNL.

Figure 1: Deformed vanes.

DESIGN PARAMETERS

The vane parameter design was done assuming 15 mA of Ag^{15+} beam (q/A = 7.2) with 0.2 π mm mrad (nor. rms) of injection beam transverse emittance. The operating frequency and vane length were retained as 100 MHz and 2.0 m respectively. The beam extraction column voltage applied to laser plasmas was set to 60 keV which corresponds to 8.3 keV/u for Ag^{15+}. The output beam energy was maximized within the limited length. The final modulation factor reached 3.0. Those values are summarized at Table 1 and Fig. 2.

Table 1: Parameters of the RFQ LINAC

RFQ Type	4rod
Frequency	100.1 MHz
Designed Charge to Mass Ratio	1/7.2
Length	2.0 m
Cell Number	143
Input Energy	8.3 keV/u
Output Energy	270keV/u
Designed Vane Voltage	73 kV
Maximum m	3.0
Q value	4500

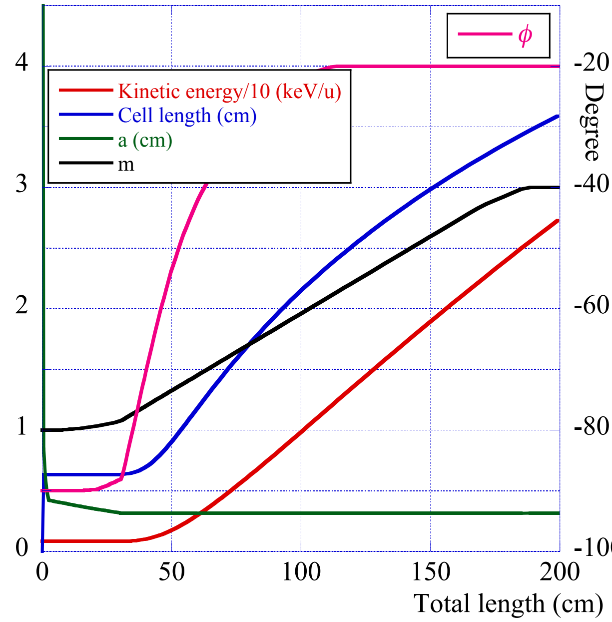

Figure 2: Vane parameters vs. length.

INJECTED BEAM PROPERTY

For the beam commissioning, we used carbon and iron beams. Carbon beam production from the laser ion source had been well established and we focused to examine iron ablation plasma using a plasma analysis beam line as shown in Fig. 3 prior to the beam test.

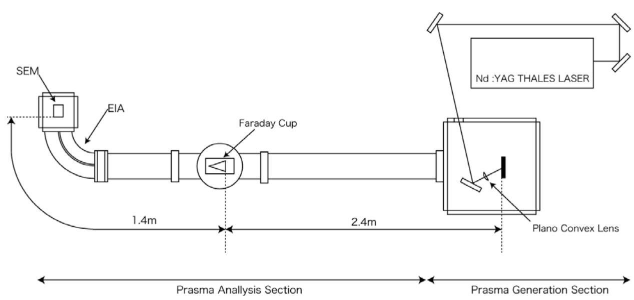

Figure 3: Plasma analysis beam line.

In order to analyze the charge state distribution of the iron plasma, different voltages were applied along a 90 degree electro static bend that ended in a secondary electron multiplier. Particles are bent along a radius of curvature that is determined by the particle's charge to mass ratio and velocity, and the applied voltage. So for a given applied voltage, only particles of a given velocity for a specific charge to mass ratio will reach the detector and produce an electrical signal. Therefore it is possible to determine the charge state that caused a signal simply by looking at the time it occurred. A typical waveform taken in the experiment is shown in Fig. 4. Then, by scanning through a range of voltages, the charge state distribution in a single beam pulse was derived. The integrated charge state distribution is described in Fig. 5.

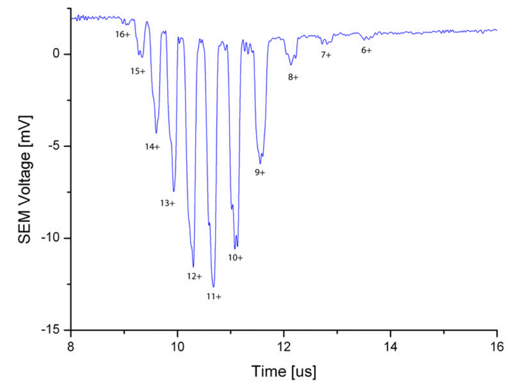

Figure 4: Detected signal by secondary electron multiplier.

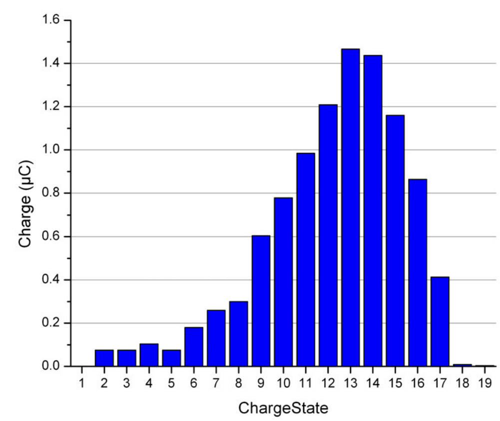

Figure 5: Charge state distribution.

The most abundant charge state was 13+. In this experiment, a Nd-YAG laser (Thales SAGA230) was used. The laser energy and pulse width were 1.5 J and 6 ns respectively. The focal length of the final focusing lens was 100 mm which gave around 10^{12}W/cm^2 on the iron target surface.

BEAM TEST

First, carbon beams were injected into the RFQ to check the all the experimental equipment working properly[4]. And then iron target was installed. The experimental layout is shown in Fig. 6.

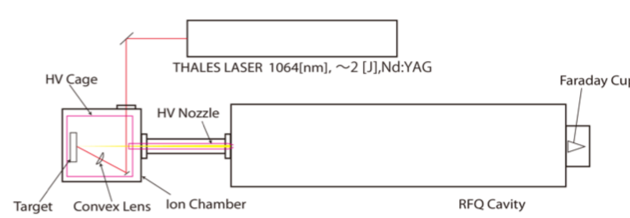

Figure 6: Experimental layout.

The extraction nozzle, facing to the RFQ entrance, has a inner diameter of 4 mm. The peak total current of the

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injected iron current was 18 mA which was estimated based on the plasma analysis experiment result.

Figure 7 shows the recorded beam current after the RFQ. The injection column voltage was scanned. The blue signal is at 33.3 kV, which corresponds roughly to Ag^{14+} injection beam energy. The accelerated beam comprised 14+ and higher charge states. At the very low injection energy, the beam could not be captured by RF buckets and was not accelerated at all as shown as the red signal. The un-accelerated beam appeared from 3.5 to 6 µs which is slower than the bunched accelerated beam. The green signal shows an intermediate condition. Only the very high charge state ions were accelerated; most of the injected beam was just transported through the RFQ with the plasma extraction beam energy. The RF power was 77 kW.

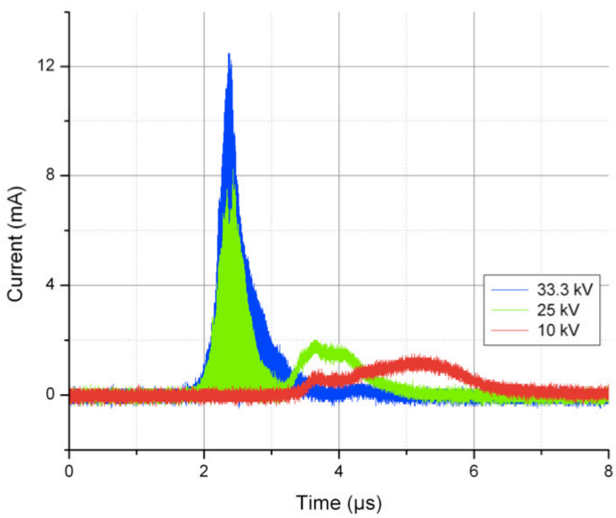

Figure 7: Experimental layout.

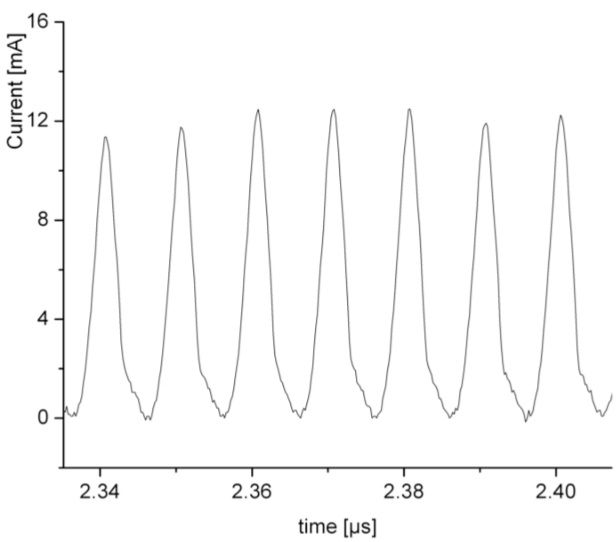

Figure 8: Bunched structure after the RFQ.

Figure 8 shows a magnified version of the accelerated beam peak. The RF bunching expected is readily apparent, with peaks separated by the expected 10 ns. The peak accelerated current reaches about 4 mA with the DC average over 4 periods. The total accelerated charge was plotted as shown in Fig. 9.

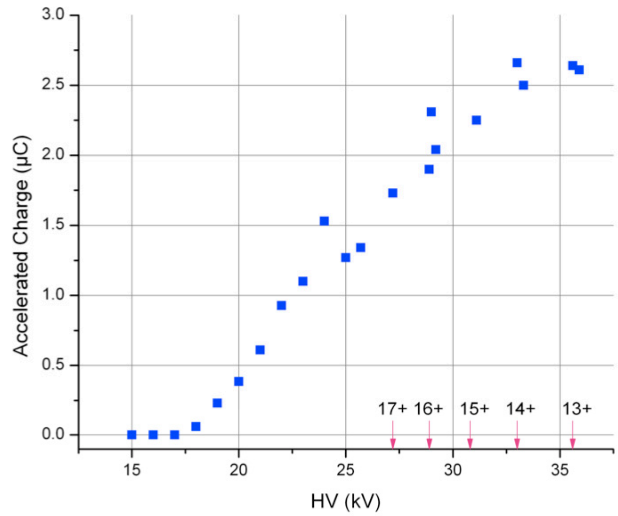

Figure 9: Accelerated charge vs. injection voltage.

We didn't analyze the accelerated beam with a bending magnet yet, however, the bunched structure was clearly observed. This means the beam was accelerated properly with iron beam with DPIS.

SUMMARY AND PLAN

We commissioned the RFQ with replaced new vanes. We confirmed that the entire system is working as we expected. Now we are preparing silver beam acceleration with applying solenoid confinement DPIS. Also analyzing beam lines will be built to measure a current of each charge state ions and transverse beam emittances.

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