Magnetic field clamp in direct plasma injection scheme†

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A new set of vanes for the radio frequency quadrupole (RFQ) accelerator was commissioned using the highly charged iron beam in Brookhaven National Laboratory (BNL). To supply high intensity heavy ion beams from a laser ion source (LIS) to the RFQ, the direct plasma injection scheme (DPIS)[1,2] with a confinement solenoid was adopted. By in troducing the solenoid field, the plasma expanding angle can be controlled and the capability of LIS drastically enhanced[3]. In an LIS, the peak value of beam current is inversely proportional to the cube of the plasma drift distance. In order to stretch the ion beam pulse length, a longer plasma drift length is required, which simultaneously reduces the current amplitude. The solenoid can compensate this reduction effortlessly. however, the solenoid field causes another difficulty. The fringe field of the solenoid overwraps the ion extraction area where exist a static extraction electric field and focusing RF field. Generally, when we apply a magnetic field on a high-gradient electric field, discharges may be induced. To accelerate Fe^{14+} in the DPIS set up, the nozzle emits ions that have a static voltage gap of 33.3 kV overlaid by the fringe of the RFQ field of ±20.5 kV at 100 MHz. A magnetic field of few hundreds Gauss is present in the same space simultaneously. To investigate the fields, OPERA2D and 3D [4] were used.

Figure 1 shows an example of the electric static field simulation by OPERA2D. The nozzle is filled by the laser plasma, and ions are extracted by the field gradient between the vanes and nozzle. The plasma and the extracted ion beams move along the *z* axis from bottom to top in the figure. The plasma sheath is formed at the top of the nozzle. Another high electric field is induced towards the end wall of the RF cavity. When we apply a solenoid field, magnetic flux of the same direction as the electric field is induced. When discharges occur, electrons emitted from the vane surface are accelerated by the electric field towards the nozzle and guided by the magnetic field. This easily triggers further discharges. To prevent this, the copper-made end wall flange, which is a part of the cavity, was replaced by a plated iron flange. Another iron-made disk called barrier flange was also installed. The magnetic field was reduced to a few gauss, as shown in the simulation in Fig. 2. This modification enabled us to apply sufficient extraction voltage on the nozzle.

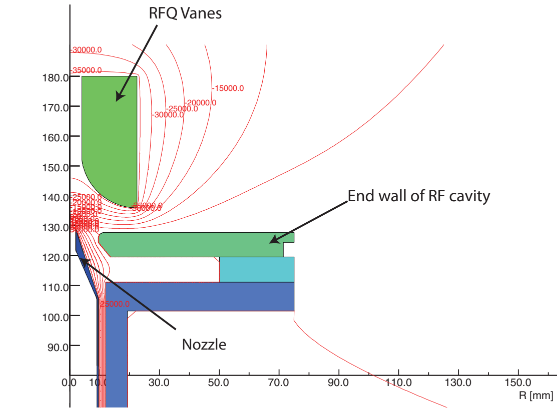

Figure 1 Static electric field simulation at the beam extraction region.

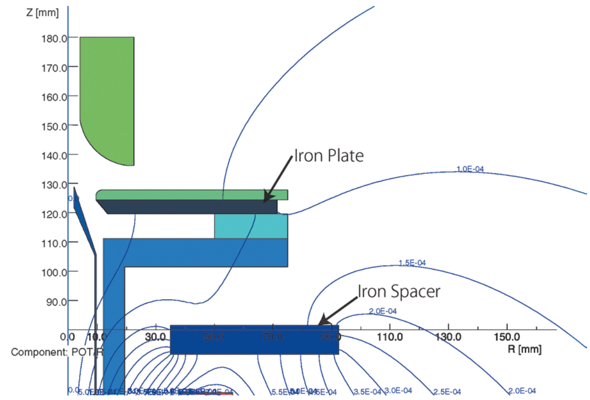

Figure 2 Magnetic field simulation with the field clamps.

Using the modified magnetic structure, we observed the accelerated iron beams at the downstream of the RFQ. The pulse width was about 1.5 μs on using a 1.0 m length solenoid filed at 105 G. The RF power was adjusted to maximize the current, which was about 3 mA. The result was obtained without beam analysis behind the RFQ, and the currents include all accelerated particles. The test was not intended to obtain maximum beam current; however, we could confirm that all the devices are working as intended.

References

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4) OPERA-TOSCA, www.cobham.com

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