Study of the Extraction Configuration of NIRS-HEC Ion Source

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Abstract

In order to increase the beam intensity of NIRS-HEC, we have studied the extraction configuration with He^{+} ions. It was observed that the high voltage extraction is effective to increase the beam intensity when the extraction current density is high. The results of computer simulation agreed excellently with the experimental data.

1 Introduction

A 10GHz ECR ion source (NIRS-ECR) and a PIG ion source supply heavy ions for cancer treatment and fundamental experiments, in Heavy Ion Medical Accelerator in Chiba (HIMAC), National Institute of Radiological Sciences (NIRS) [1], [2]. A typical intensity of C^{4+} ion is about three hundred eμA with both sources and satisfies medical requirement. For heavier ions than Ar^{8+}, however, higher beam intensities are desired especially by physicists, biologists etc. So an 18GHz ECR ion source with High-voltage Extraction Configuration (NIRS-HEC) was installed in March, 1996 [3], [4].

Features of NIRS-HEC are as follows. One of the most important features of NIRS-HEC is the high extraction voltage to reduce space charge effects in the beam extraction region. The insulation between the plasma chamber and the extraction electrode was carefully designed. Major components of the source including the plasma chamber, mirror magnet, permanent magnet, and other devices, are put on a high voltage platform. The maximum extraction voltage reaches to 60kV. The other feature is a strong magnetic field to confine the source plasma in a small region. The maximum axial field strength reaches about 12kG. A radial size of the plasma chamber is made as small as 40mm, so that a sextupole field strength of 11kG is easily obtained.

2 Experimental method

In order to improve the beam intensity, we must optimize the extraction configuration [5]. The extraction electric field is affected by the extracted beam current and distribution due to the space charge effects. An optimum extraction field can be searched by moving the extraction electrode or by changing the extraction voltage. In order to investigate optimum extraction configuration, we measured the extracted beam currents at the different extraction voltages. The distance between the extraction slit and the extraction electrode, the extraction current density and the mirror magnetic field of the extraction side are also varied in the measurements to search optimum configuration of the extraction system. The experimental data were compared with the simulation results.

Figure 1 shows a schematic layout of the extraction system of NIRS-HEC. An analyzed beam current I_{acc} is measured at the front of the analyzing magnet as a current from the platform to the ground. An unextracted current I_{ext} which flows into the extraction electrode is also measured. The total extracted current I_{total} from the extraction slit is estimated as a sum of I_{acc} and I_{ext}. Although there is an ambiguity in I_{ext} due to the secondary electron emission from the electrode, it does not give serious effects on the discussions described here. The extraction voltage V_{ext} is applied to extraction electrode. A symbol d_{ext} denotes a distance between the extraction slit and the extraction electrode. Helium gas was used in this experiment. Because, it has the simplest charge state distribution to compare the experimental data with the simulation.

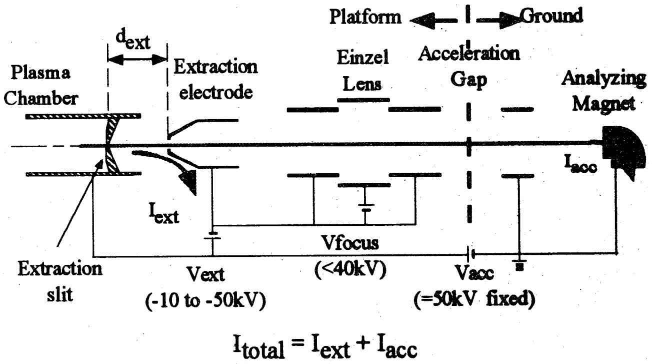


Fig. 1 A layout of the extraction system of NIRS-HEC ion source

3 Experimental results

3-1 Dependence on extraction voltage

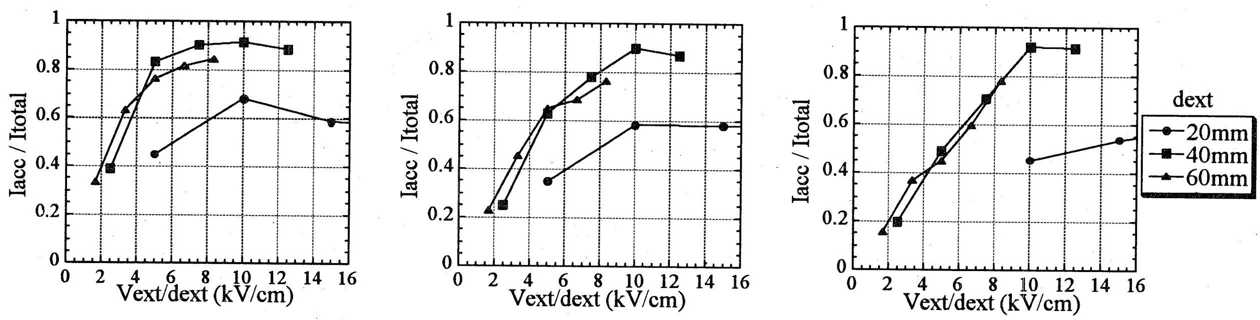
Dependencies of I_{acc} on extraction voltages are shown in Figs. 2a) to 2c). In these figures, I_{acc} is normalized with I_{total} and horizontal axis is given in form of electric field strength instead of V_{ext}. The experimental conditions are as follows. The pulse length was 5ms, the repetition rate was 2Hz. The mirror magnet current of extraction side is fixed at 600A, V_{ext} was varied from 10 to 50kV, d_{ext} was varied 20, 40, and 60mm. I_{total} was tuned to 6, 9 and 12mA.

It is clear from these figures that higher extraction fields are needed at higher extraction currents to overcome the strong space charge defocusing effects. Low values of I_{acc}/I_{total} for d_{ext}=20mm suggest that the distortion in the axial extraction field may affect on the focusing characteristics of the extraction electrodes.

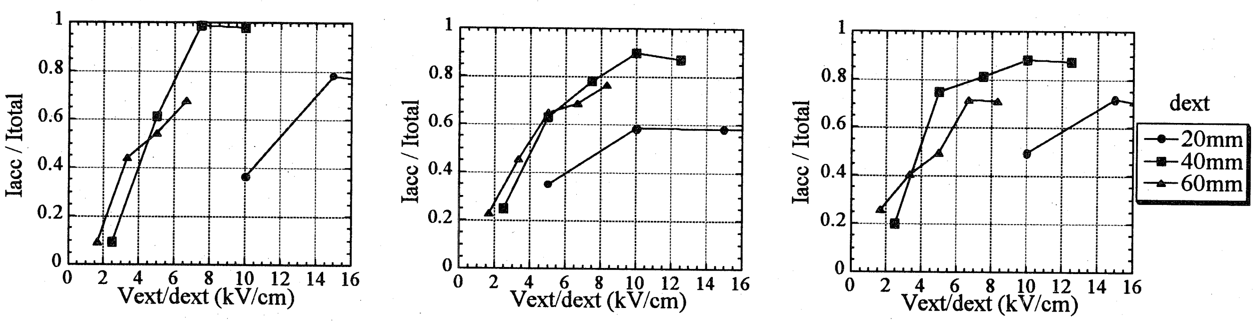
3-2 Relation of magnetic field, I_{total}, and I_{acc}

Figure 3 shows a ratio of I_{acc} to I_{total} for different values of mirror magnet field in the extraction side, M2, at 400, 600, and 700A. In these measurements, I_{total} was fixed at 9mA. Other parameters are the same as those described in 3-2.

Effects of the magnetic field distribution on the extracted current will be discussed in 4-2.



a) b) c)
Fig. 2 V_{ext}/d_{ext} - I_{acc}/I_{total} (d_{ext}=20,40,60mm, M2=600A)
a) I_{total}=6mA, b) I_{total}=9mA, c) I_{total}=12mA



a) b) c)
Fig. 3 V_{ext}/d_{ext} - I_{acc}/I_{total} (M2=400,600,700A, I_{total}=9mA)
a) M2=400A, b) M2=600A, c) M2=700A

4 Simulation Results

4-1 Effectiveness of high extraction voltage

Figure 4 and 5 show the typical results of simulations. In these calculations, we use the FUGUN code [5]. This is a modified Herrmansferd's EGUN code by adding a 1-D sheath theory to solve the particle motion at the extraction region in plasma. The axial position of the plasma meniscus is determined with the Child-Langmuir law on the space charge limited emission. In Fig. 5, calculated values of I_{acc} are given for different I_{total}, comparing with experimental results. In these calculations, values of M2 and d_{ext} are fixed at 600A and 40mm, respectively. The simulation results agreed well with the experimental data.

4-2 Flux density distribution in extraction region

Extracted current intensity depends on the initial ion density distribution at the extraction slit. In the TrapCAD code, the cross sectional density distribution of the ions is estimated with three different assumptions; the density distribution is homogeneous, the density distribution is proportional to the magnetic flux density at the slit and the density distribution is proportional to the magnetic flux density multiplied by the plasma volume along the magnetic flux line [6]. (See Fig. 6)

The calculated results are shown in Fig. 7 together with experimental values.

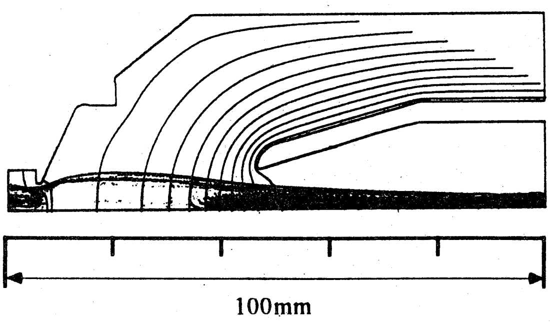


Fig. 4 Typical trajectory simulated by FUGUN

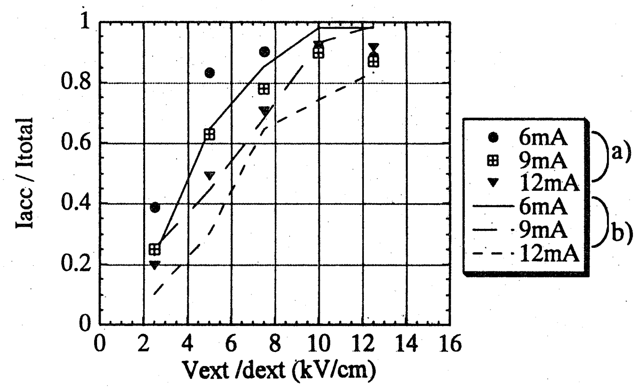


Fig. 5 Calculated dependence of I_{acc} on V_{ext} for different values of Itotal together with the experimental data
a) Experiment b) Calculation

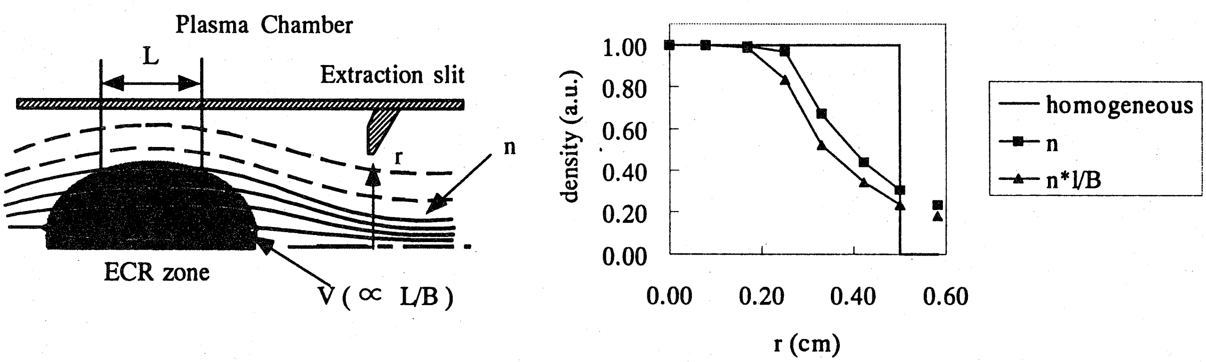


Fig. 6 Flux density distribution by TrapCAD

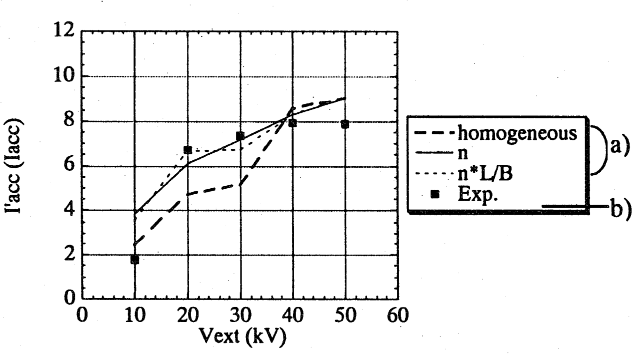


Fig. 7 Experimental and calculation results of
V_{ext} - I_{acc} (M2=700A, d_{ext},=40mm, I_{total}=9mA)
a) Calculation b) Experiment

5 References

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