SIMULATION STUDY OF SPACE CHARGE EFFECTS FOR A 100keV-150mA CLASS DEUTRON SOURCE

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Abstract

Recently ion sources providing high current beams with low emittance are required for accelerators to develop fusion materials [1]. A high current beam diverges easily because of its strong space charge effects at the beam extraction area. We have examined utilizing a simulation code "IGUN" [2, 3, 4] in order to obtain the best parameters for a high current deuteron beam having a low emittance.

The arrangement of the extraction electrodes designed for the simulation is an accel-decel extraction system constituted from four electrodes: a plasma electrode, a medium electrode, an electron suppresser electrode and a ground electrode. The applied voltages to the plasma electrode and the ground electrode were fixed for 100kV and 0V, respectively. The applied voltages to the other electrodes were changed. The range of the applied voltage to the medium electrode was between 30kV and 45kV, and that to the suppresser electrode was between -2V and -22kV. We investigated the emittance and a beam radius by changing the voltages.

In this study, the best parameters were obtained that 45kV to the medium electrode and -6 ~ -10kV to the suppresser electrode. Under the condition, the beam emittance of 0.032π mm mrad was achieved.

INTRODUCTION

Proton and Deuteron beams over 100mA come to be utilized widely, as expanding the application of particle accelerators. Such high current beams diverge more easily than low current beams because of their strong space charge effect. For realizing a low emittance and high current beam, it is necessary to consider the space charge effects and to add focusing forces properly. Therefore we have studied how the emittance and the beam radius were changed by the applied voltages to extraction electrodes, in order to obtain the best beam quality. However, it is difficult to carry on an examination using the ion source providing beam current over 100mA actually. It makes us to study employing simulation codes for such a high current beam. In our research, the simulation code IGUN which had been developed by R. Becker and W. B. Herrmannsfeld was employed.

The beam current was fixed 150mA. The shape of extraction electrodes was designed for minifying emittance under the condition as extraction voltage was 100kV and extraction current was 150mA. Some voltages applied extraction electrodes were changed under the fixed extraction system.

IGUN SIMULATION

Simulation conditions

The arrangement of the extraction electrodes designed for the simulation is shown in Fig. 1. An accel-decel extraction system was constituted from four electrodes: a plasma electrode, a medium electrode, an electron suppresser electrode and a ground electrode. In the simulation, the voltages applied to the plasma electrode and that to the ground electrode were fixed: the voltage applied to the plasma electrode was 100kV and that to the ground electrode was 0V. The voltage to the medium electrode (V_{med}) and that to the suppresser electrode (V_{supp}) were changed.

In order to determine the range of V_{med} and V_{supp}, it was taken into account that a high voltage applied between electrodes often causes an electric breakdown in an actual .ion source. We calculated the electric field between the medium electrode and the suppresser electrode, and that between the suppresser electrode and the ground electrode. The value of 60kV/m was adopted as the limitation of the electric field. The value of the

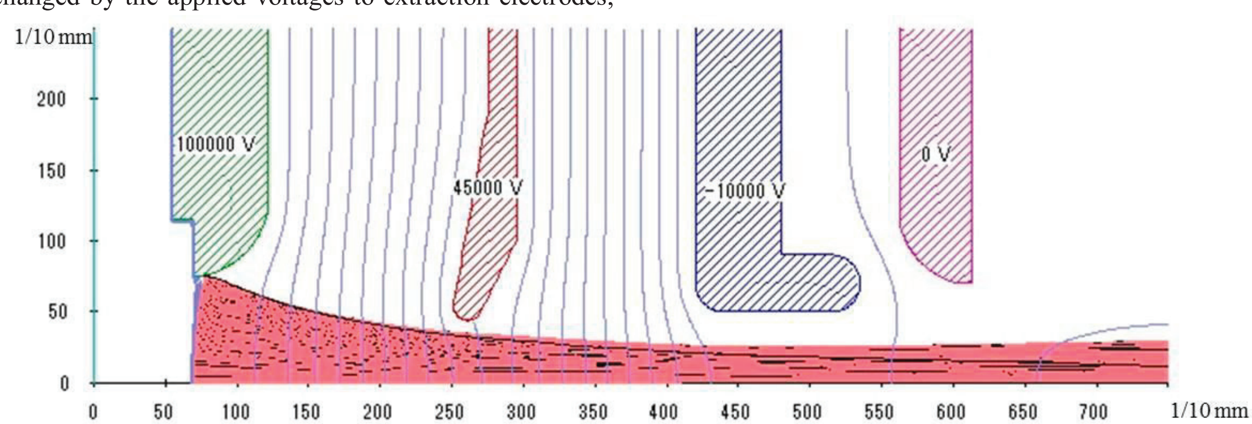

Figure 1: Arrangement of extraction electrodes.

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electric field was calculated by dividing the electric potential difference between the electrodes by most proximity distance. Table 1 shows the most proximity distances of each pair of the electrodes. In this calculation, it was assumed that V_{med} ranged from 30kV to 45kV and V_{supp} ranged from 0V to -30kV. Fig. 2 shows the electric field between the medium electrode and the suppresser electrode. Only in the case that V_{med} was 45kV and V_{supp} was -30kV, the electric field was over 60kV/m. Fig. 3 shows the electric field between the suppresser electrode and the ground electrode. The electric field of this area was dependent on only V_{supp} and independent on V_{med}. When V_{supp} was higher than -24kV, the electric field became over 60kV/m. In addition to those results, generally V_{supp} was not 0 to suppress leaking electrons through the suppresser electrode. Therefore, the parameters which provide the lowest emittance were searched in the range from -2kV to -22kV of V_{supp}.

From the result of the calculation, it was determined the range of the voltage applied to the medium electrode was changed from 30kV to 45kV and that to the suppresser electrode was changed from 2V to -22kV. Voltages applied to the electrodes are shown in Table 2. Some cases were eliminated that the beam cannot be extracted because of too low extraction voltage and that the beam hits either electrode because of too strong or too weak focusing force by the electric fields.

A typical beam profile of the deuteron beam is shown in Fig. 1. The beam emittance and the beam radius were measured at the position of axial distance 75mm; the right end of the figure. This position was defined “the emittance measure surface”.

Simulation results

The results of the emittance and the beam radius show that a higher V_{supp} is suitable to the beam extraction. Fig. 4 shows the emittance change for V_{med} and V_{supp}. When V_{supp} was low, V_{med} of 45kV was proper to achieve a low beam emittance. The emittance of 0.031-0.033π mm mrad was achieved at the V_{supp} between -6kV and -20kV. However, once V_{supp} was higher than -20kV, the emittance became 0.045π mm mrad in the case that V_{med} was 45kV. The change of the beam radius for the V_{med} and V_{supp} at the emittance measure surface is shown in Fig. 5. Mostly, the beam radius decreased with an increase of V_{supp}; this means that the focal length of the extraction system increased with the increase of V_{supp}. This change must be taken into account in the future design of the low energy beam transfer (LEBT). In the case that V_{med} was 35kV or 45kV, the emittance became large at V_{supp} of about -20kV, at which the emittance became large in the case that V_{med} was 45kV.

The emittances obtained when V_{supp} was 45kV were smaller than the others; and they were nearly constant in the range from -6kV to -20kV of V_{supp}. The graph of the beam radius shows that higher V_{supp} was preferable in this range; however, the beam radius is able to focus at a later focusing system in LEBT. Moreover, in order to decrease risk of an electric breakdown, a lower potential is preferable. Because of these conditions, the best parameters to achieve a lowest emittance are 45kV of V_{med} and -6kV to -10kV of V_{supp}. The emittance was 0.032π mm mrad under this condition.

Table 1: most proximity distance between the electrodes

	Medium electrode – Suppresser electrode	Suppresser electrode – Ground electrode
Most proximity distance	12.5 mm	3.98 mm

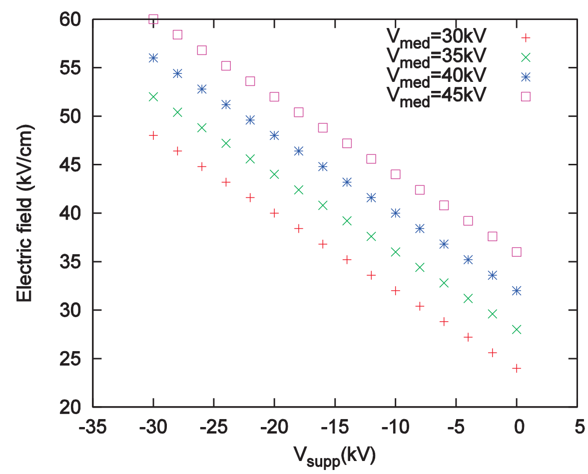

Figure 2: Electric field between the medium electrode and the suppresser electrode.

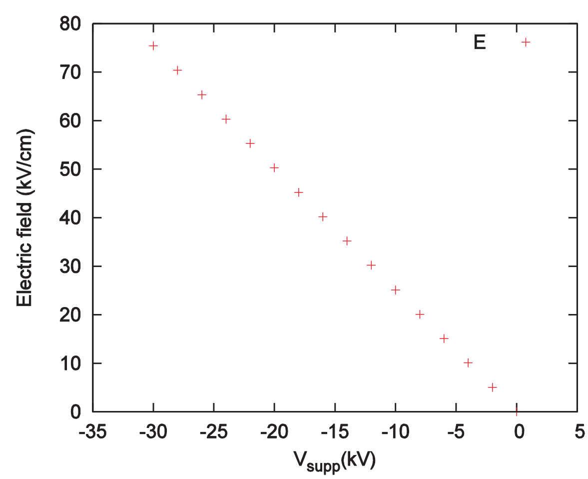

Figure 3: Electric field between the suppresser electrode and the ground electrode.

Table 2: Voltage of electrodes at design

Plasma electrode	Medium electrode	Suppresser electrode	Ground electrode
100kV	30kV~45kV	-2V~-22kV	0V

CONCLUSION

To investigate the best parameters to achieve a high current beam having low emittance, we conducted a simulation study employing IGUN code. The emittances and the beam radii were obtained by simulations changing the parameters: the applied voltages to the medium electrode and the suppresser electrode. In consideration of the possibility that an electric discharge occur, the electric field between the medium electrode and the suppresser electrode and that between the suppresser electrode and the ground electrode were calculated and the case that the electric field was over 60kV/m was eliminated. The emittance became lowest in the case that V_{med} was 45kV, and V_{supp} was between -6kV and -20kV. In this range of V_{supp}, the beam radius decreased with an increase of V_{supp}. However, the beam radius can be adjusted at the later focusing system. Taking reduction of the risk of an electric breakdown into account, the best parameters were decided that 45kV of V_{med} and -6kV to -10kV of V_{supp}. Under this condition, the emittance of 0.032π mm mrad was achieved.

In the next step, LEBT through which a high current beam can be transferred with less emittance growth will be designed, taking into account the results of this study: the change of the emittance and the beam radius by changing the voltages applied to the electrodes.

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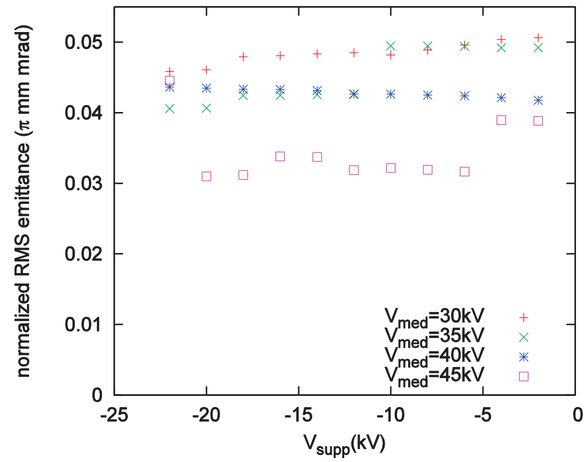

Figure 4: Emittance change for the voltages applied to the medium electrode and the suppresser electrode.

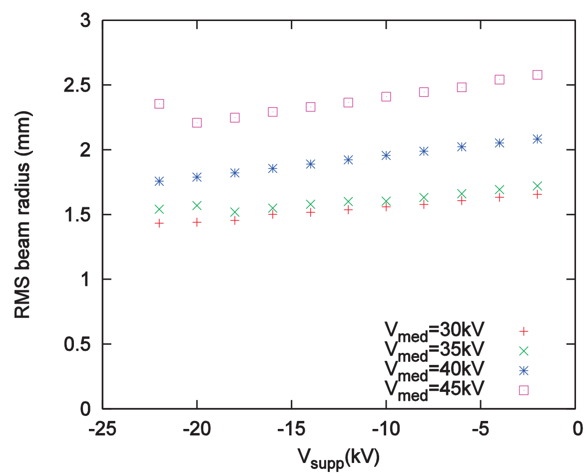

Figure 5: Beam radius change for the voltages applied to the medium electrode and the suppresser electrode.

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