#83

Space Charge Compensation Study of High Intensity Ion Beams

Z Shen[1,2], L T Sun[1,2], Z H Jia[1], X Fang[1], C Qian[1], and H W Zhao[1,2]

[1] Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS), Lanzhou 730000, China

[2] School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

E-mail Address: shenzhen@impcas.ac.cn

Abstract

The space charge effect is one of the key factors affecting ion beam transport and ion beam quality, especially for low-energy high-intensity ion beams. It can be partially compensated by the secondary electrons produced from the ionization of residual gas molecules in the beam pipe, and we are interested in the accurate value of this compensation degree. In this paper, we use a Three-grid Energy Analyzer (TEA) to measure the secondary ion energy distribution of the beam, which is corresponding to the compensated beam potential distribution. To have accurate evaluation of the compensation degree, it is essential to adopt a proper transverse distribution of the ion beam, other than using the Gaussian theorem for uniform beams. The results of space charge compensation degree study for singly charged ion beams with a 2.45GHz microwave ion source and for multiply charged ion beams with a high charge state ECR ion source are presented.

Space Charge Effect and Space Charge Compensation

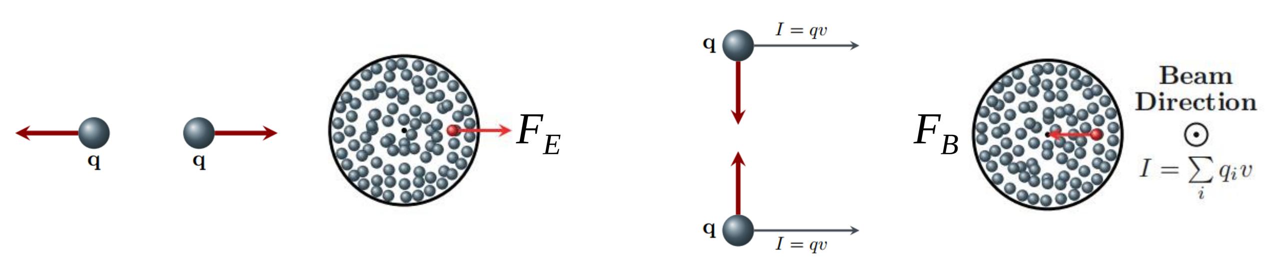

Figure 1. The space charge effect of charged particle beams.

The space charge effect of charged particle beams consists of two forces in opposite directions, the electric force F_E of particles with like charges and the magnetic force F_B caused by the induced magnetic field. The relation of F_E and F_B can be expressed as:

$$F_E / F_B = \frac{qI}{2\pi\varepsilon_0 v}\frac{2\pi}{qv\mu_0 I} = \frac{1}{\varepsilon_0\mu_0 v^2} = \frac{c^2}{v^2}$$

For low energy ion beams($v << c$), $F_E >> F_B$, the magnetic force is negligible.

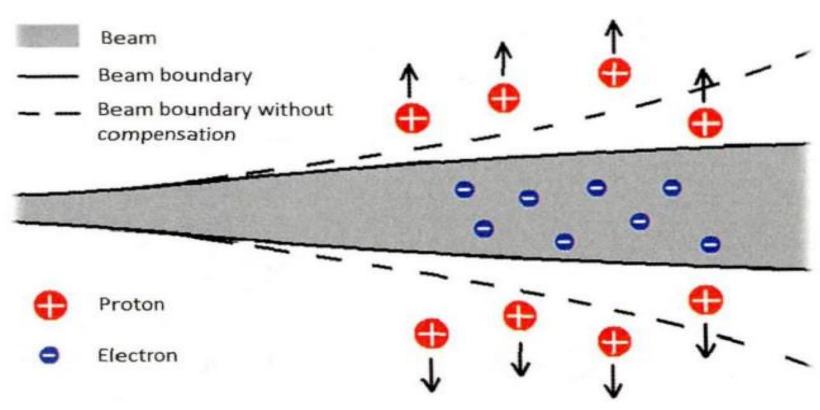

Figure 2. Space charge compensation of residual gases.

The space charge effect can be partially compensated by the secondary electrons produced from the ionization of residual gas molecules in the beam pipe. The degree of space charge compensation is defined as:

$$\eta = 1 - \frac{\Delta\phi_c}{\Delta\phi_{un}}$$

In this equation, the compensated beam potential difference from the beam center to the boundary $\Delta\phi_c$ can be obtained by measuring the secondary ion energy distribution, while the uncompensated beam potential difference $\Delta\phi_{un}$ is usually calculated with a uniform beam potential distribution as:

$$\Delta\phi_{un} = \phi(0) - \phi(r_{beam}) = \frac{I}{4\pi\varepsilon_0 v}$$

However, the actual beam distribution is hardly uniform, especially for highly charged ion sources with hexapole magnets. So we managed to calculate the beam potential distribution by measuring the beam current distribution.

Measurements of Space Charge Compensation Degree

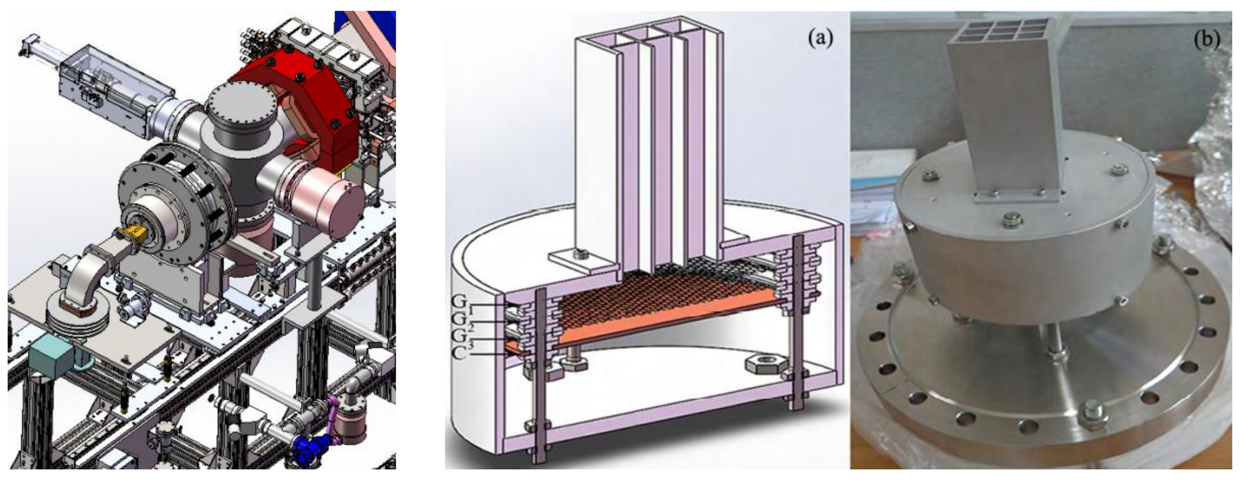

Figure 3. The 2.45GHz ion source and the TEA.

We use a TEA to measure the secondary ion energy distribution of Ar^+ and He^+ beams produced by a 2.45GHz microwave ion source. By sweeping the voltage of G_2, we can obtain the variation of collecting current of secondary ions. Part of the measurement results fitting with three straight lines are shown in figure 4.

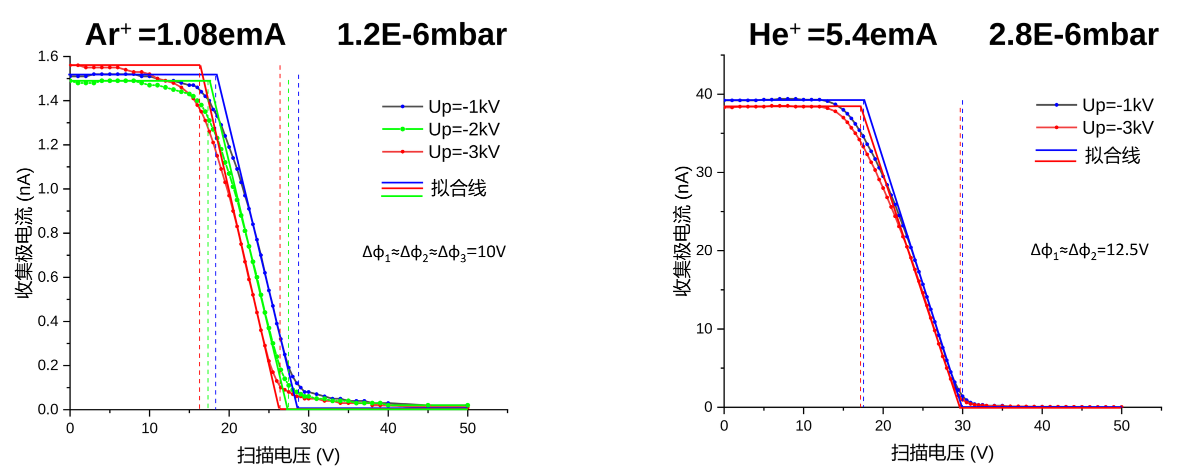

Figure 4. Secondary ion energy distribution of Ar^+ and He^+ beams.

Based on the image of the fluorescent at the same spot of the transport line with the TEA, we perform the grey level distribution analysis to obtain the transverse distribution of the beam current. According to the superposition principle of electric potential, the electric potential of any point i can be expressed as:

$$\phi_i = \sum_{j \neq i} \frac{I_j}{2\pi\varepsilon_0 v} \ln \frac{d_{j\to 0}}{d_{j\to i}}$$

In this way, we can get the uncompensated beam potential distribution and the uncompensated beam potential difference $\Delta\phi_{un}$.

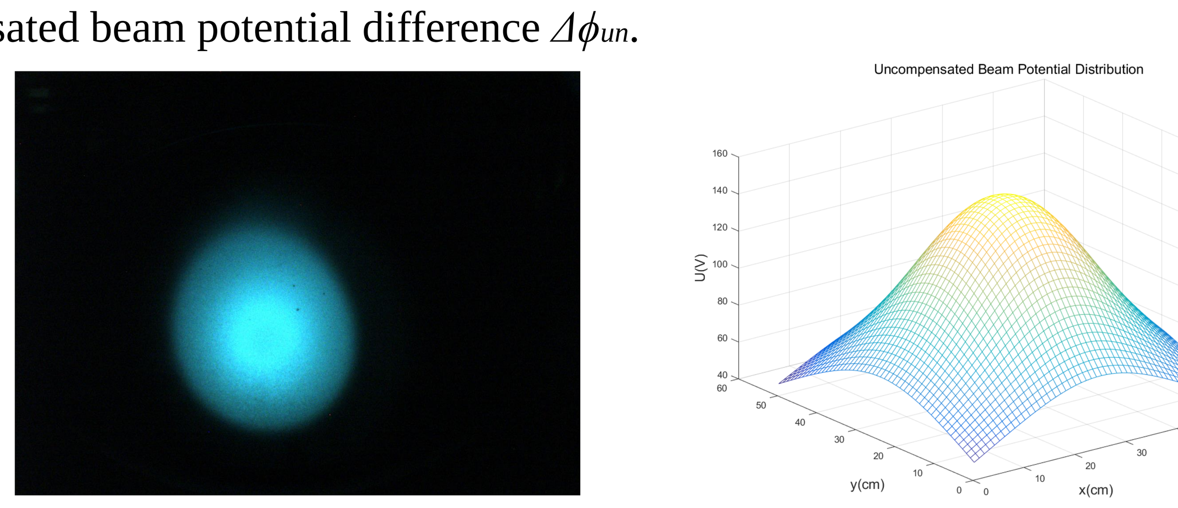

Figure 5. Example of the fluorescent image and the uncompensated beam potential distribution.

The comparison of space charge compensation degree of uniform beams and gray level analyzed beams are listed in table 1.

Table 1. Comparison between uniform beams and gray level analyzed beams.

	Ar^+ =1.08emA			He^+ =5.4emA	
Puller Voltage	-1kV	-2kV	-3kV	-1kV	-3kV
$\Delta\phi c$ (V)		10		12.5	
Uniform $\Delta\phi un$ (V)		23.9		38.5	
Gray $\Delta\phi un$ (V)	39.6	38.2	38.9	64.2	68.6
Uniform η		0.581		0.675	
Gray η	0.747	0.738	0.743	0.805	0.818

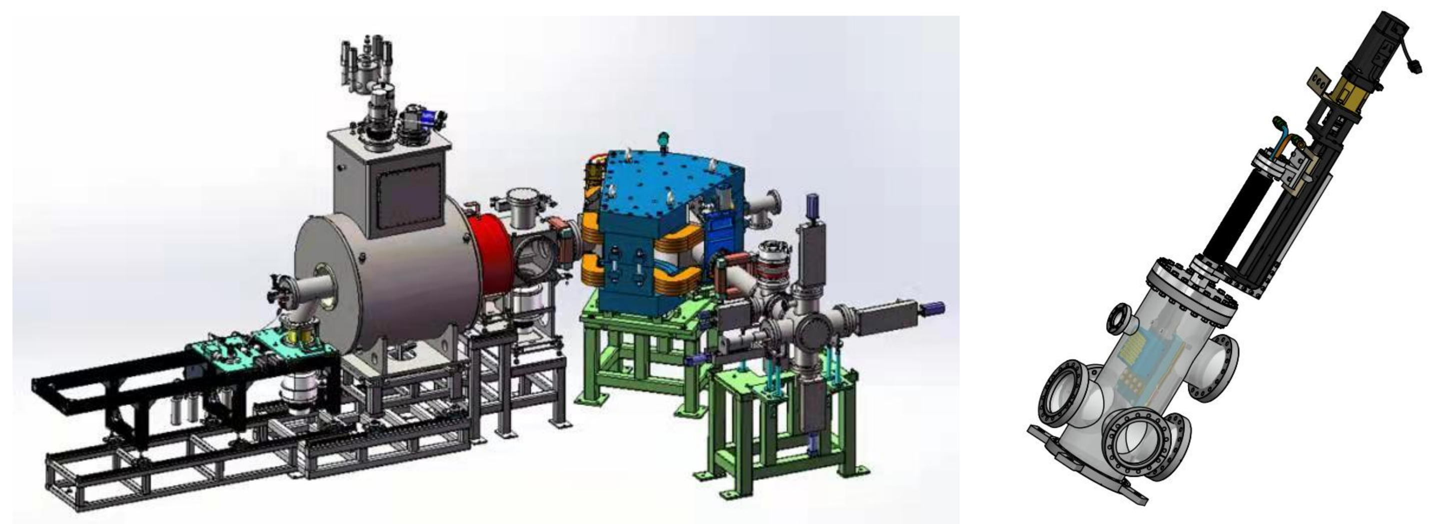

Figure 6. HECRAL ion source and the 128-channel picoammeter system.

A 128-channel picoammeter system and the TEA were placed at the same spot after the beam diagnostics chamber of HECRAL LEBT. We changed the focusing solenoid field to see the influence of the beam distribution on the measurement results. Part of the measurement results are shown in figure 7 and figure 8.

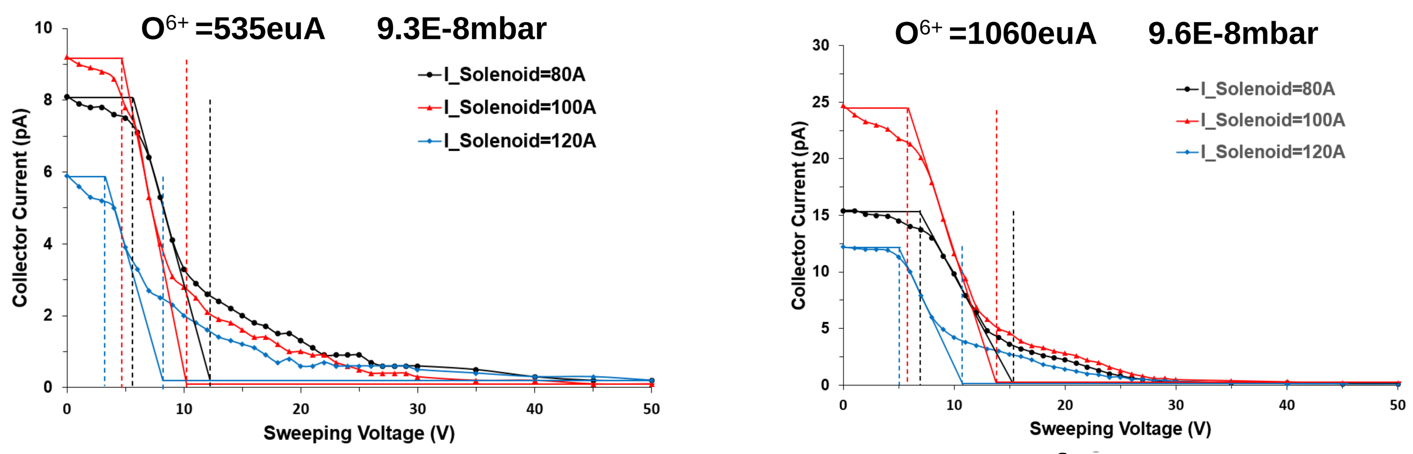

Figure 7. Secondary ion energy distribution of O^{6+} beams.

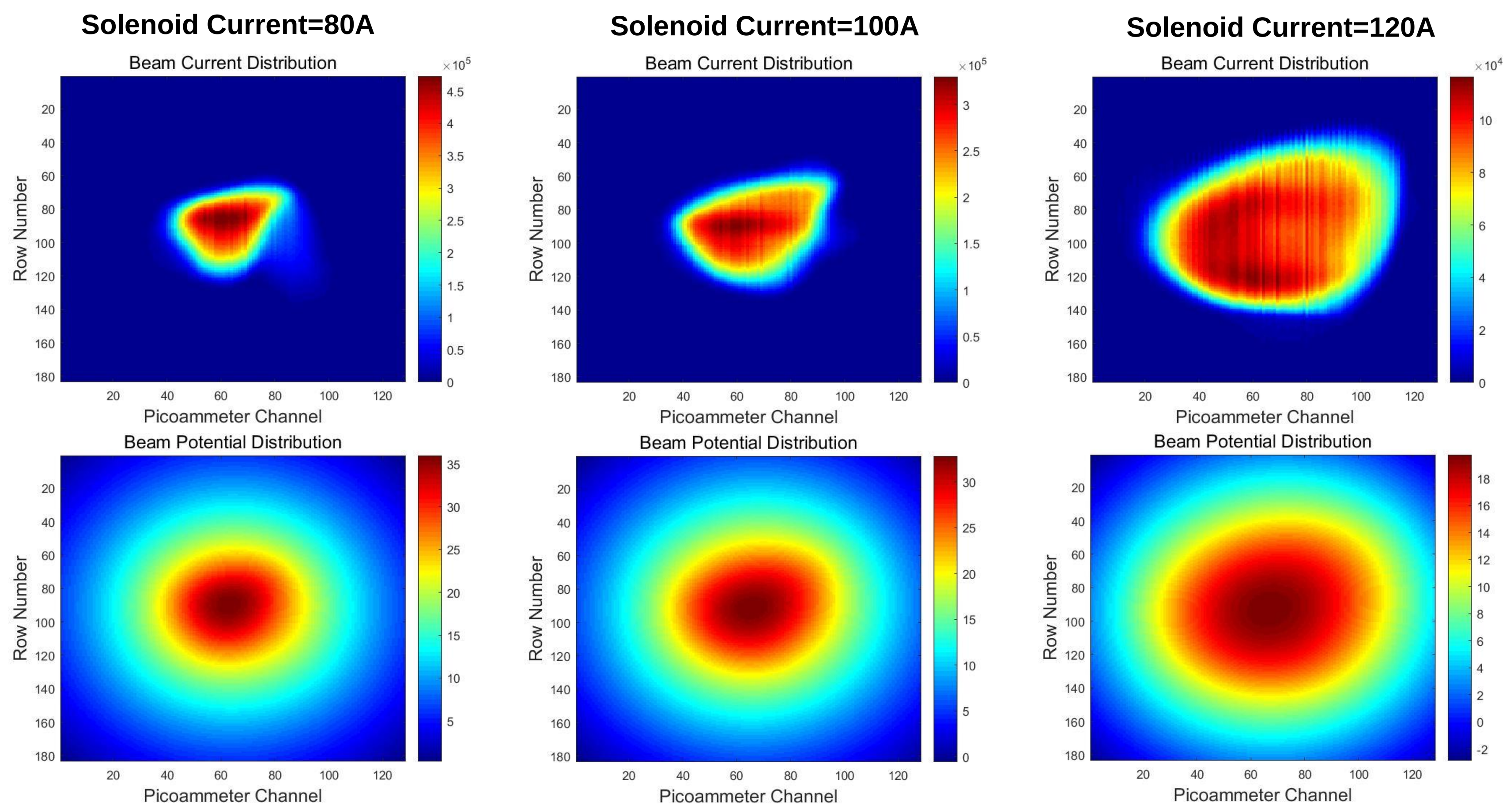

Figure 8. Beam current and uncompensated beam potential distribution of 1060euA O^{6+} beams.

Table 2. Comparison between uniform beams and current analyzed beams.

	O^{6+} =535euA			O^{6+} =1060euA		
I_Solenoid (A)	80	100	120	80	100	120
$\Delta\phi c$ (V)	6.6	5.4	5	8.4	8.0	5.8
Uniform $\Delta\phi un$ (V)	4.5	4.6	4.5	8.8	9.1	8.2
Current $\Delta\phi un$ (V)	12.2	10.5	9.0	23.4	20.5	14.6
Uniform η	-0.471	-0.170	-0.104	0.050	0.125	0.296
Current η	0.460	0.487	0.442	0.641	0.61	0.604

Conclusion

I. A proper transverse beam distribution influences greatly on the degree of space charge compensation, especially for highly charged ion beams.

II. For the same extracted beams, different puller electrode voltage or focusing solenoid field will not change the degree of space charge compensation.