§9. Collection of Beam Profile by Modifying Aperture Shape of Steering Grid

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Hydrogen negative ions (H⁻) are neutralized by the collision with neutral hydrogen molecules during beam acceleration, and the H⁻ ions are separated to accelerated hydrogen atoms (H°) and electrons called stripped electron. Some part of those H° and striped electron beams spread and collide on the electrode grid at the beam downstream. Assuming the beam perviance is kept constant, current value of H⁻ ions is proportional to 5/2 power of the beam energy, and the heat load increases as the H⁻ current the goes up. The H⁻ neutralization during acceleration is inevitable and there are two methods to reduce the heat load. One is to reduce the neutral gas pressure inside the acceleration gap, and another is to make smaller the grid area exposed by the heat load. In order to satisfy both of the conditions. multi-slot grounded grid (MSGG) has been developed and introduced to the beam injection for the large helical device (LHD). In the 7ᵗʰ LHD experimental campaign, FY2003, the maximum power of 5.7 MW has been attained using a beam line with two negative ion sources consisting of the MSGG.
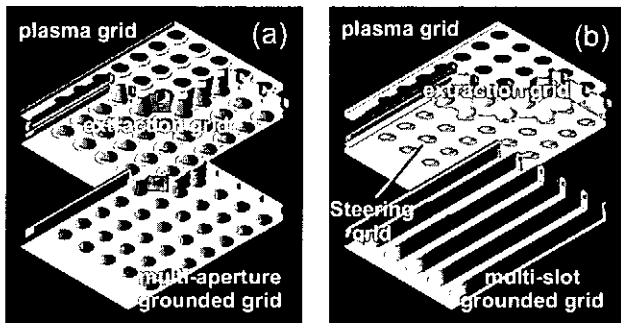

Fig. 1. Cut views of beam accelerators with multi-aperture grounded grid (a) and multi-slot grounded grid (b). The H⁻ beam is accelerated from upward to downward direction in these figures.

Although the MSGG has an advantage for high power beam injection, the grid includes a demerit on beam focusing. Figure 1(a) and 1(b) indicate the cut views of the beam accelerator with multi-aperture grounded grid (MAGG) and MSGG. As shown in Fig. 1(a), all the electrode grids of beam accelerator have circular apertures for the MAGG, and curvatures of equipotential surfaces near all the apertures are axial symmetry. On the other hand, the axial symmetry brakes down in the MSGG. The profile of each beamlet, which is a single beam extracted from each aperture of plasma grid (PG), is distorted by symmetry mismatching between steering grid (SG) and MSGG, and this causes two focal conditions for parallel and perpendicular direction to the long axis of the slot.

The extraction grid (EG) and SG is connected electrically, and extraction voltage (Vex) and acceleration voltage (Vac) are applied to the gaps between PG and EG and between SG and MSGG, respectively. The width of

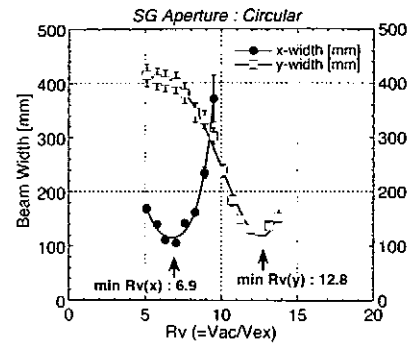beam profile changes by varying the voltage ratio of acceleration voltage to extraction voltage ($Rv=Vacc/Vext$).

Fig. 2. Typical e-folding half width of beam profile as a function of voltage ratio (Rv) of acceleration voltage (Vac) to extraction voltage (Vex). The closed circles and open squares indicate the widths parallel and perpendicular to the long axis of MSGG slot, respectively. The data was obtained using an accelerator with MSGG and SG circular apertures (ϕ13 mm).

Figure 2 shows the e-folding half width of beam profile measured by a calorimeter array at the beam focal point. The width was measured using a small-scaled negative ion source consisting of a combination of a SG with circular apertures and a MSGG. As shown in Fig. 2, the minimum beam widths parallel (x-width) and perpendicular (y-width) to the long axis of MSGG-slot are observed at the different voltage ratios, which are indicated as $min\ Rv(x)$ and $min\ Rv(y)$. The beam convergence of x-direction is better than that of y-direction and H⁻ current density is higher in the lower voltage ratio at the same acceleration voltage, thus the voltage ratio is set at a value close to the $min\ R(x)$ in practical beam injection. The beam profile, therefore, is elongated in y-direction. Due to this elongation, the injection port of LHD-NBI#1 was damaged in FY2003.

A racetrack shaped aperture is applied for SG to reduce the incontinence of the focal conditions. The long axis direction of the racetrack aperture is set parallel to the slot long side, y-direction. The racetrack SG aperture gives the counter distortion to each beamlet in the elongated direction caused by the slot of grounded grid. The $min\ R(x)$ and $min\ R(y)$, consequently, approach each other comparing to the circular SG aperture case as shown in Fig. 3. By modifying the shape of SG aperture, port-though efficiency for beam injection will increase, and the damage of the injection port is considered to decrease.
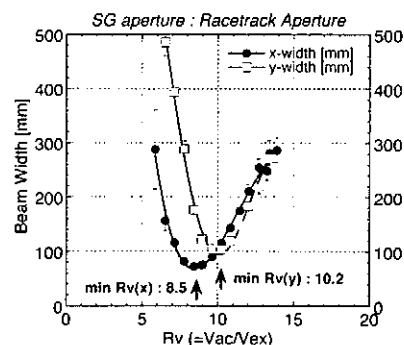

Fig. 3. Typical e-folding half width of beam profile as a function of voltage ratio. The data was obtained by using an accelerator with MSGG and racetrack SG apertures (ϕ10x13 mm).