§8. Improvements of a Negative Ion Source with Multi-Slot Grounded Grid

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The enhancement of injection power in neutral beam injection is depended mainly on the improvement of ion sources, whose key issues are the followings. The first is to construct the beam accelerator with high voltage acceptance to increase beam energy. The next is to enhance of the production efficiency of hydrogen negative ions (H^-) inside the arc chamber. The last is to increase the beam transport efficiency such as the efficiency passing through beam injection port. A new type of negative ion source has been developed and applied for LHD-NBI since the 6th campaign year of LHD experiment, FY2002. The ion source consists of a combination of a steering grid, SG and a multi-slot grounded grid, MSGG. A schematic cut view of the beam accelerator with the MSGG are shown in Fig.1. As shown in Fig. 1 the MSGG has a higher beam transparency than conventional multi-aperture grounded grid, MAGG. The accelerator, therefore, accepts larger heat load onto the grounded gird, and it is available to increase the beam energy higher than ever. Using the new ion sources with the MSGG, we achieved the maximum injection power of 4.4 MW at the beam energy of 180 keV in FY2002.

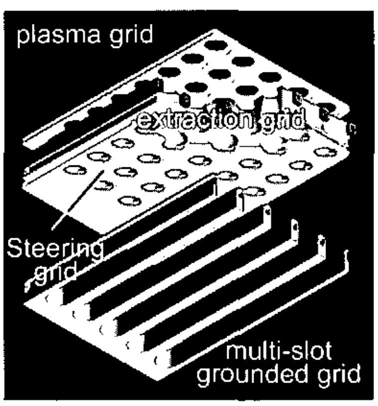

Fig. 1. A cutting view of the beam accelerator with the MSGG. The H^- beam is accelerated from upward to downward direction in this view.

Although the injection power and energy increased drastically using the MSGG, power degradation was shown at high-energy range as shown in Fig. 2, which indicates the injection power, P_{inj} as a function of beam energy, E_B. The power data was obtained in the first beam line of LHD-NBI with two negative ion sources. Potential ratio applied at acceleration gap to extraction gap and distances between the grid gaps were kept constant to obtain the data. Assuming the beam perviance did not change in the plot, the curve-A proportional to $E_B^{5/2}$ indicates the saturated beam power due to space charge limit of H^- current. The power, however, fits to a curve-B at the energy more than 160 keV. The curve B is proportional to E_B. This suggests the production rate of H^- ions is insufficient to the beam extraction field in this energy range.

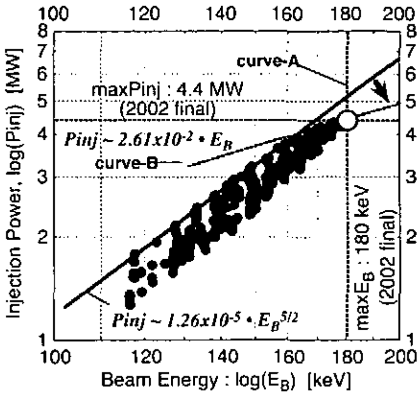

Fig. 2. Neutral injection power, P_{inj} plotted as a function of the beam energy, E_B. Below the energy of 160 keV, space charge limited injection power follows the line-A proportional to $E_B^{5/2}$ (curve-A) and to E_B (curve-B) below and over the energy, respectively.

Two-steps improvements have been applied to increase the H^- production rate before FY2003. The first step is temperature adjustment of plasma grid, whose surface is considered to convert hydrogenous positive ions to H^- ions. The conversion ratio is a function of surface workfunction, which is a function of vapor pressure and temperature of the plasma grid. The grid temperature in FY2002 was 210 oC and was lower than the empirical optimum temperature of 240-250 oC. The second step is adjustment of arc-plasma balance by increasing the total number of filaments form 24 to 26. The additional two filaments located at central parts of the arc chamber of the ion source.

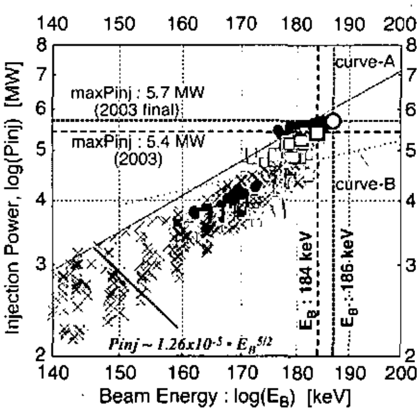

Fig. 3. Injection power plotted as a function of beam energy. The cross points (x) indicates the data before improvement. The open squares and solid circles correspond to the data after adjustment of plasma grid and after balancing the arc plasma, respectively.

In Fig. 3, injection power is indicated as a function of beam energy for comparison of the status is compared before and after the two-steps improvement. The maximum injection power goes up to 5.4 MW at the beam energy of 184 keV after the adjustment of the plasma-grid temperature. The injection power attained to higher value of 5.7 MW (186 keV) by making the arc-plasma balance. By those two improvements, injection power followed to $E_B^{5/2}$ curve (curve-A) in tae figure.