§18. Numerical Analysis of Negative Ion Sources

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Since 1998 NBI experiments has been continuously done by using negative-ion based neutral injectors in LHD. In order to increase stored energy of LHD plasma, it is necessary to improve negative hydrogen ion H^- sources for the neutral beam line. For this purpose we started to code some programs. There are mainly two codes to calculate for magnetic lines of force and electron trajectories inside ion sources.

The tracer of magnetic lines of force calculates the magnetic field at any point by superimposing the field caused by all permanent magnets and filaments inside a given ion source. Trajectory of the field is numerically integrated. Magnetic structures of an ion source of LHD-NBI BL1 and a newly designed source were compared by using the code.

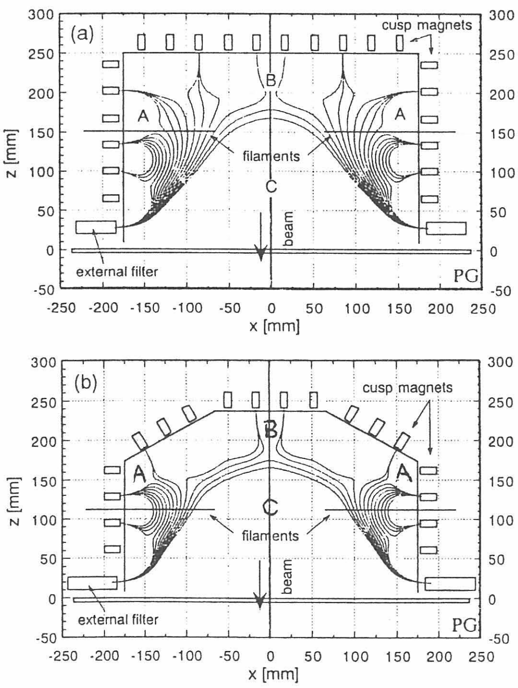

Fig. 1. Bundles of magnetic lines of force in an ion source for LHD-NBI #1 (a), and a new ion source (b). In these figures smaller squares indicate cusp magnets and larger ones indicate the external magnets.

Figure 1a and 1b show bundles of magnetic field lines in a LHD ion source and a new source, respectively. In these figures cross sectional views in shorter sides of ion sources are indicated; the beam directions of H^- are indicated by arrows in those figures. Each magnetic line of force starts from filaments to the inner walls of those ion sources. In the LHD source there exist three symmetric domains which are denoted by domains A, B and C. The domain C is caused by external magnetic field. Plasma inside this domain becomes a direct seed of H^- ions extracted as ion beam. On the other hand, background plasma is formed inside the domains A and B. The filed lines in domains B connect and expand near top side wall in Fig 1(a), and particle loss is expected around there. In case of the new ion source these areas are cut by changing the cross sectional shape of the source. The magnetic field lines connect walls less than those of LHD source and domain A is surrounded tight magnetic field caused by wall cusp magnets. It suggests particle loss becomes lower in case of the new source.

Our ion sources have long vertical sides which are y axes in Fig. 1. In such sources the arc plasmas distribute one-sided along long axes. To understand a correlation between direction of electron drift, another code was applied to calculate electron trajectories inside arc chambers. In this code the electrons start from filaments with given initial energy corresponding to arc voltages. To simplify and to extract the drift direction of electron some atomic and ionic collisions were ignored in this calculation.

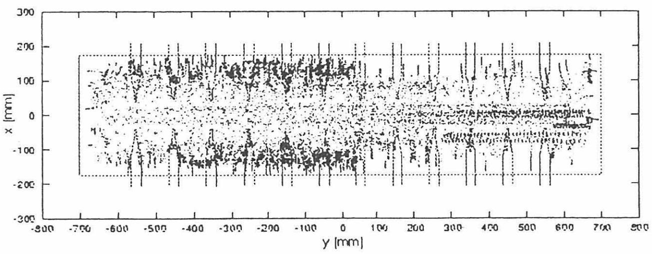

Fig. 2. Calculated electron motions inside an arc chamber for LHD NBI #1. The figure shows a view from back side plate of the chamber; the horizontal and vertical directions indicate long and shot sides of the source. The beam direction is normal to this paper.

In Fig. 2 calculated electron trajectories are shown in case of LHD source. The trajectories are plotted in a time interval of 20 psec. Those electrons start from two filaments at y position of 50 mm. There are two ensembles of drift electrons. One of them displaces on the right hand side and to the central part of the figure, and the other shifts on the left hand side and to both sides of the upper and lower walls. The former electrons are emitted from near the tips of filaments, and the latter ones are from leg parts of the filaments. The shift of electron concentration is caused by gradient B drift. Electrons emitted from leg parts of filaments are trapped by local magnetic mirrors of cusp magnets (domain A in Fig. 1), while electrons from filament tips are bound by mirror of the external filter field (domain B in Fig. 1). In this calculation electron concentration the shifts on left hand side. In two ion sources for LHD-NBI #1 the arc plasmas shift in opposite directions and the tendency observes in this calculation.

The shift of calculated electron concentration is changed by alignment of the magnets surrounding arc chambers and emitting points of electron at filaments. The filament shape and magnetic structure of the new ion source were shaped up by using the correlation between practical plasma shift and calculated electron shift.