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# Compensation of ion deflection and disposal of electrons in the ion source test facility for ITER neutral beam injectors

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Two Heating and Current Drive Neutral Beam Injectors (H&CD NBI) are planned in ITER to deliver a total of 33 MW of heating power. Each NBI is designed to operate at 1 MV and 40 A current in Deuterium and 870 kV and 46 A in Hydrogen; to guarantee a sufficient neutralisation efficiency, negative ions are used [1]. In order to optimise the ion source operation, a full-size negative ion source test facility will be built in Padova [2]; the source is equipped with a plasma grid (PG) at -100 kV, an extraction grid (EG) at -90 kV, and a grounded grid (GG). All grids are composed of 4x4 beamlet groups, each one made of 5 (horizontally) and 16 (vertically) beamlets for a total of 1280 [3]. For the ITER H&CD NBI negative ion source it is required that the co-extracted electron current is not larger than the negative ion current; other sources of electrons within the accelerator are stripping reactions undergone by negative ions and ionisation of the background gas. To decrease the number of extracted electrons and to reduce the energy of electrons in the vicinity of the PG (which destroy negative ions before extraction), the reference design adopts a horizontal magnetic field produced by a current flowing in the plasma grid and by two permanent magnets on either side of the source [4]. A recent improvement [5] results in a more uniform horizontal magnetic field across the PG, obtained by adding current conductors beside the PG, moving the return conductors close to the source back, and inserting a ferromagnetic layer in the GG. The magnetic field downstream of the GG is about zero so that the negative ions are not deflected downwards, unlike the reference configuration [6]. As a consequence however the electrons exiting from the accelerator are not deflected onto a plate at the vessel bottom; so they might hit the downstream components. Another series of magnets (suppression magnets), located in the EG, produces a vertical magnetic field which changes sign from one row of beamlets to the neighbouring one. Such vertical magnetic field deflects the co-extracted electrons onto the EG itself so that the great majority of them is not accelerated up to full energy. As a side effect, however, also the negative ions are slightly deflected horizontally.

This paper presents the results of an activity aimed at reducing the ion deflection and, at the same time, disposing of electrons, applied to the model of the full-size negative ion source for ITER [7]. The geometry used in the computations is shown in Fig. 1; more details are in [8].

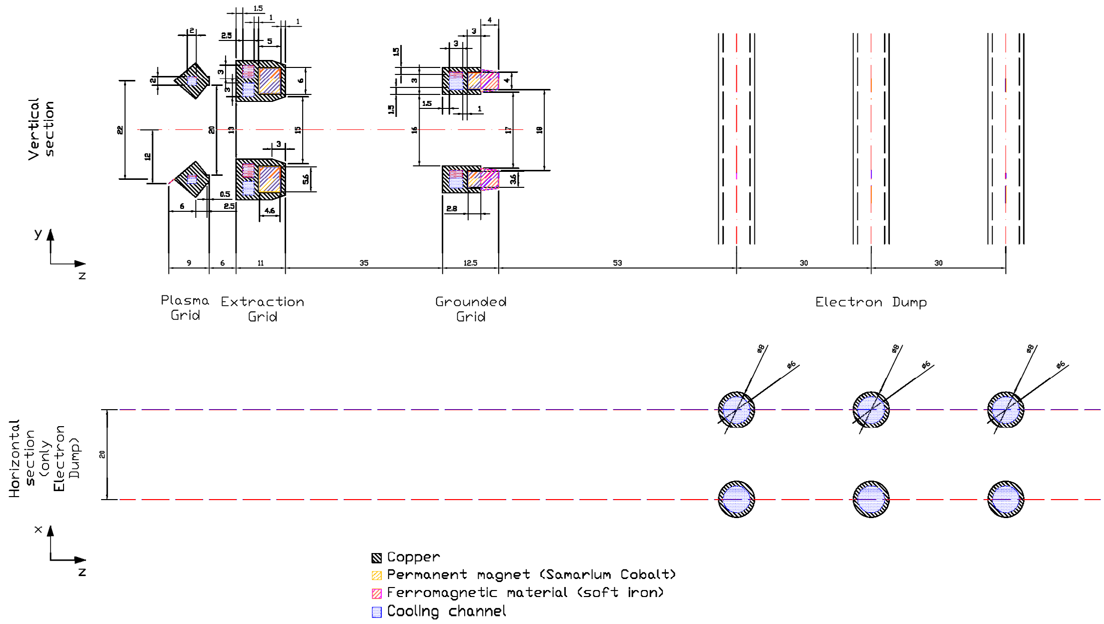


Fig. 1: Geometry of accelerator and electron dump: vertical section (top) and horizontal section (bottom).

The horizontal deflection of negative ions, induced by the suppression magnets, can be reduced by means of permanent magnets inserted in the GG. However, since permanent magnets produce a symmetric magnetic field on both sides of the GG and the energy of the particles has no large variation across the GG, the net effect on all particles should be quite limited. To obtain the required compensation effect, it is proposed that a slab of ferromagnetic material with holes corresponding to the grid apertures is located on the downstream side of the GG. This way, as long as the ferromagnetic material is not saturated, the magnetic field on the downstream side of the GG is strongly reduced and the magnetic field on the upstream side compensates for the horizontal deflection of the particles. Such slab of ferromagnetic material also reduces the horizontal field and the vertical deflection of negative ions downstream of the GG. The horizontal deflection of negative ion trajectories due to the suppression magnets (computed using the OPERA code [9]) was about 6.5 mrad in the absence of compensation magnets. With suitable compensation magnets in the GG, having the same polarity as in the EG but lower remanence (0.382 T instead of 0.96 T) and smaller size ($2.8\times 3.6\ mm^2$ instead of $4.6\times 5.6\ mm^2$), the deflection is reduced virtually to zero.

Possible ways to dispose of electrons exiting the accelerator have been investigated in the past. Magnetic fields were proposed to deflect the electrons downwards onto suitably cooled plates, which were located at the bottom of the vacuum vessel and at the entrance of the neutraliser; another possibility envisaged four horizontal plates at the exit of the GG [10]. The main disadvantages of such solutions are the large angle with which the particles hit the single electron dump plate (resulting in an energy flux of a few tens of $MW/m^2$) or the overall dimensions of the multiple plates, which can also be an obstruction for beam diagnostics.

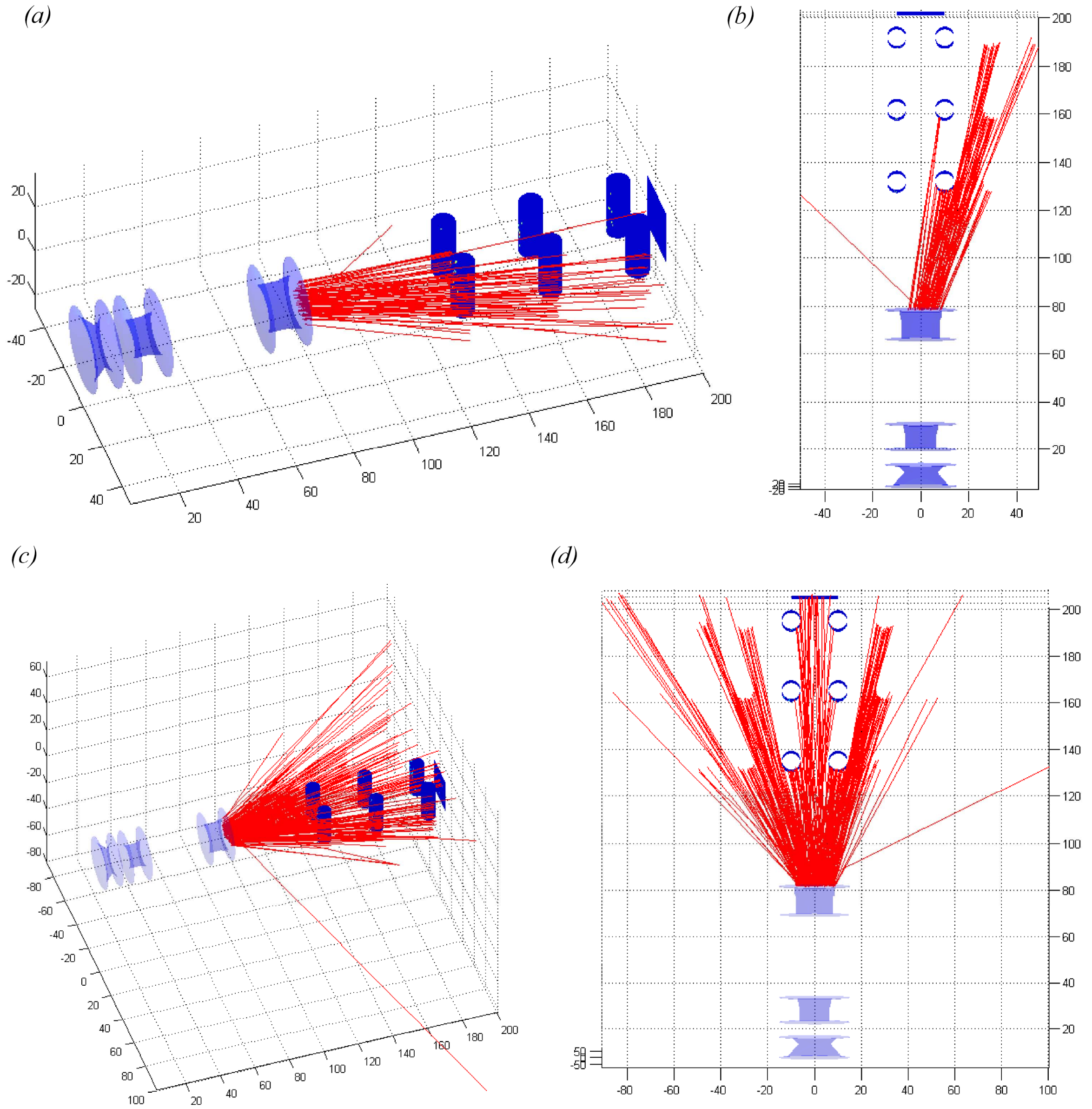


Fig. 2: Electron dump: simulation by EAMCC of coextracted electrons, iso view (a) and top view (b); simulation of secondary electrons, iso view (c) and top view (d).

Another possibility which has been explored is the horizontal deflection of electrons onto suitable plates. This solution can be realised using five electron dump plates, each one dedicated to a column of four beamlet groups [11]; however it turns out again that the size of the plates is quite large (in [12] such an electron dump is called “blinker dump” and the plates are 300 mm long). Another possibility consists in the insertion of the electron dump plates in between the beamlet columns: each dump plate receives the power associated to one beamlet column only and the attack angle can be quite small, spreading the power over a large surface; the dump plates can be only some centimetres long.

Further work over the proposal in [11] has allowed devising a modified solution, in which the vertical plates are substituted by arrays of pipes, distributed so as to intercept most of the electrons (Fig. 1). The simulations are performed after computing the electric field by the code SLACCAD [13] and then by running EAMCC [14] to compute the trajectories of primary and secondary particles; separate runs are performed for co-extracted electrons and for negative ions. After the GG the particle trajectories are assumed to be straight lines and they are followed until they hit one of the pipes or they reach the simulation boundary. The deflection of electron trajectories due to the compensation magnets can be seen in Fig. 2.

This magnetic configuration gives a total power associated to accelerated electrons of about 1 MW (611 kW due to co-extracted electrons and 390 kW due to secondaries); out of these, only 31 kW escape the electron dump and continue their path; all the escaping electrons are secondary particles, namely the co-extracted electrons are sufficiently bent by the suppression magnets so that they cannot exit from the beam source and the electron dump.

Based on the results presented herein, thermo-mechanical analyses have been carried out to design the cooling system of the electron dump [7]; the influence on pumping efficiency is still to be assessed. Moreover, generation of secondary electrons and bouncing of escaping electrons on the pipes will be the subject of future work.

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