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Thesis TITLE:

3D Modeling of the magnetized plasma neutralizer for neutral beam injection (NBI) system of the future Fusion reactor (DEMO)

Abstract

NBI is the main heating system of the future Fusion reactors (DEMO). Its mission will be to ignite and sustain the Fusion reactions over long time periods in the high temperature reactor core (plasma) via beam injection of hydrogen atoms, so called energetic neutral beam, of very high power (70 to 150MW) and high energy (1-2MeV).
Such requirements joined in one system exceed the present technological state of the art settled for ITER. This very challenging design should use new concepts merging the generation and manipulation of very intense beams but improving the existing energetic yield of the system. Indeed, the electrical efficiency of the future Fusion reactor depends very closely of the re-circulating power into the reactor elements, such as NBI. Hence, the efficiency of the heating system becomes one of the main constraints of DEMO and it should be twice better than for ITER.
Therefore, the NBI of new generation with very high yield has recently proposed by CEA Cadarache jointly with other France universities with the financial support of ANR (National Research Agency). Prior to its experimental realization, the numearical modeling can help to adjust and confirm the new design in order to overcome some technological and scientific barriers.
LPGP is one of the project partners and it developed several numerical codes to simulate the ITER NBI such as negative ion (D-) extraction from the plasma source (ONIX-3 code), NI acceleration (ONAC-3), and their neutralization by interacting with a gaseous target (code OBI-3). All these codes are dealing with “3D plasma” and uses Particle-in-Cell (PIC) approach considering the interaction between the particles via Monte Carlo.
The interaction of the ion beam with the gas (ITER neutralization principle) generates a weakly ionized secondary plasma which surrounds the beam and neutralizes the beam space charge leading to a maximum efficiency of 55% neutralization for ITER.
On the contrary, new generation of NBI for DEMO is designed to use a laminar flowing slab of high density beam, which opens new perspectives for further improvements and developments.
(i) the photo-neutralization becomes effective using photon beams of several MW (~2 MW/cm^2 of photon flux) trapped into a high quality Fabry-Perot cavity crossing the NI beam (SIPHORE ANR project);
(ii) the neutralization by the high density magnetized plasma;
(iii) the combination of the two previous processes under high magnetic fields could lead to enhanced resonant photo-detachment (Landau states).
The research project associated to this Ph.D. thesis aims the development of the new numerical code to self-consistently model the plasma formation in the magnetized neutralizer by interaction with the high energy magnetized NI beam together with the NI neutralization and particle transport.
1 – The first approach concerns the 3D modelling of the photo-neutralizer (in vacuum; OBIP-3 Orsay Beam Injector using Photons–3D), the (laser) photons being the only process for charge stripping from the NI composing the beam. It will be followed the neutral beam features in terms of emittance and efficiency, as well as the estimation of the fraction of recovered energy from the residual charged ions at the neutralizer exit plane.
2 – Starting from OBI-3 (developed for ITER neutralizer), the new code OBIM-3 (Orsay Beam Injector with Magnetized plasma – 3D) will be created including the magnetized plasma and taking care of the much higher current density of the beam slab. This advanced plasma model should allow to quantify and predict the interaction scenario for all main involved species, originating either from the plasma or from the beam, helping thus to prevent eventually experimental drawbacks.
3 –Finally, the possibility to combine the two codes OBIP and OBIM will be analyzed and it is the thesis objective aiming to have a predictive numerical tool in order to optimize the further designs of DEMO NBI.

Additional information on the model can be found in **REF 1,2**.
This work will be performed in the LPGP team – ‘Theory and Modeling of Plasmas. Discharge & Surfaces’ jointly with IRFM/CEA Cadarache.

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Keywords : Numerical simulations, Particle-In-Cell, negative ion beam, photo-detachment, out of equilibrium plasmas, magnetized plasmas

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