Post-doctoral position – LAPLACE/GREPHE – University of Toulouse

Modeling of negative ion beam aberration for high efficiency neutral beam systems

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Context

The injection of energetic neutral deuterium atoms will be one of the major heating methods of the ITER (and future fusion reactors) plasma. The 1MeV, 16.5MW neutral atom beam will be obtained by acceleration and collisional neutralization of negative ions extracted from an inductively coupled low-temperature plasma source. The negative ions will be mainly produced by impacts of positive ions and fast neutral atoms generated in the source, on the cesiated plasma grid. These ions will be extracted from the plasma by a large positive voltage applied behind the plasma grid. Extraction of negative ions from a magnetized plasma is still not well understood.

The wall plug efficiency of a Negative ion based Neutral Beam (N-NB) system is impacted by the beam losses along the beamline which result from aberrations characterized by a highly divergent negative ion sub-population accelerated at 1MeV. It is a significant power loss on current N-NB systems, it is expected to range around 5MW on an ITER beamline for 17MW of D° injected in the plasma core. Beam aberrations is an issue which has to be minimized (suppressed) for the next generation of high efficiency (> 60%), high power (>100MW) DEMO relevant N-NB systems.

Minimizing the beam aberrations requires a complete understanding and characterization of the extraction of negative ions from the plasma and of the meniscus that forms at the boundary between the quasineutral magnetized plasma and the acceleration region.

Research Project

The goal of the proposed research is to fully understand negative ion extraction and characterize in detail by 2D and 3D particle modelling the origins of the aberrations in negative ion sources (PIC-MCC, Particle-In-Cell Monte Carlo Collisions).

Negative ion transport properties in the vicinity of the extraction aperture are difficult to assess experimentally (most of the relevant physics occurs within a few Debye lengths which is sub-millimetric in typical high power ion sources) and numerical modelling is used instead to calculate the plasma characteristics in the extraction region (shape of the plasma meniscus, physics behind the formation of a virtual cathode near the plasma grid surface, etc.). A virtual cathode arises in front of the plasma grid when the flux of negative ions emitted by the grid surface becomes space charge limited.

Attempts at modelling negative ion extraction using Particle-In-Cell Monte Carlo Collisions (PIC MCC) method have not been fully satisfactory and have sometimes led to questionable results because of the difficulty to take properly into account the boundary conditions between the plasma source and the extraction holes. The research group at LAPLACE has thoroughly studied the properties of the plasma in the magnetic filter region of the plasma source, next to the extraction region. The group is able to propose significant improvements of negative ion extraction models and has started a project in this direction.

The project for the postdoctoral fellow is to pursue this research effort and to extend the modelling of the negative ion transport characteristics to the full accelerator length:

- In a first phase, a 2D PIC MCC model will be used to better understand the physics of negative ion extraction, to calculate the transmitted negative ion beam properties (emittance), to assess if some of the aberrations hit the accelerator grids and quantify the amount of power deposited on the latter. A 2D model is compatible with the geometry of the DEMO CYBELE prototype developed at CEA Cadarache, and which consists of accelerator grids made of slits.
- The second part of the project will be dedicated to the development of a 3D PIC-MCC model of the extractor (one plasma grid aperture and the extraction grid) in collaboration with CNR-NanoTec, Bari (Italy). The distribution function of the extracted negative ions will be used as an input into a 3D PIC model of the accelerator (i.e., excluding the negative ion source plasma in order to significantly speedup the calculations).
- Lastly, the 3D electrostatic potential in the accelerator will be coupled to the EAMCC model [Fubiani et *al.*, Phys. Rev. ST Accel. Beams **11**, 014202 (2008)] in order to evaluate secondary particle production and parasitic power deposition on the accelerator parts.

Results from the calculations will be compared to the data from existing accelerators used in fusion applications. The PIC-MCC models will be massively parallel hybrid MPI/OpenMP algorithms capable to run on supercomputers.

The research will be performed in collaboration between the GREPHE (CNRS/LAPLACE laboratory, university of Toulouse, France) and P.Las.M.I (CNR-NanoTec Institute in Bari, Italy) research groups. The postdoctoral researcher will be based in Toulouse but is expected to spend time in the CNR-NanoTec Institute. Collaboration and interactions with CEA Cadarache and IPP Garching (Max Planck Institute for Plasma Physics) will also be an important aspect of the project.