Simulation of a Power Neutral Beam Injection in RFX-Mod

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1. Motivation

The 1 MW neutral beam injector originally designed for the TPE–RX reversed field pinch (RFP) experiment in Tsukuba [1] will be installed on RFX-mod in the framework of a research agreement between Consorzio RFX and National Institute of AIST. After the recent significant progress in both confinement and physics understanding in RFP's, times are mature for the use of additional forms of heating and current drive in RFP. The possibility to decouple heating and configuration sustainment (current), induce poloidal current drive to help quenching the magnetic turbulence, heat and fuel directly the volume occupied by the quasi single helicity or finally inject momentum are all means that are expected to further enhance our comprehension of the RFP physics and thus our capability to assess the viability of an RFP reactor.

2. Beam main parameters and geometry

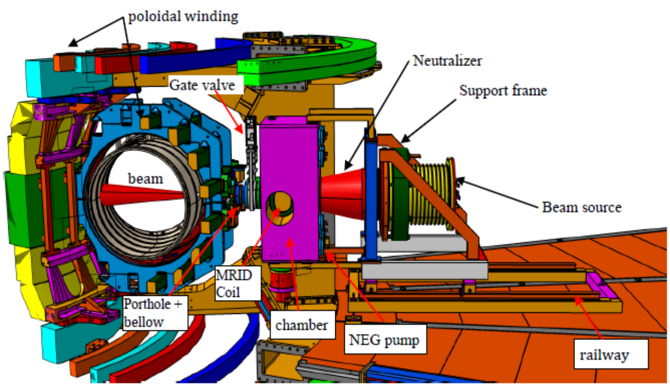

Fig. 1. Schematic drawing of the NBI installation on RFX-mod.

The injector described in Refs. 1 and 2 features an energy of 25 keV with a positive ion current that can exceed 50 A for up to 30 ms. The ion source is of hot filament type. The accelerating grids are spherical and the beam is strongly focused in order to allow the beam through narrow ports such as those in TPE-RX and RFX-mod.

Schematic drawing of NBI installation to RFX-mode is shown in Fig. 1. To pump the region between neutralization chamber and plasma, and avoid beam re-ionization, commercial (SAES Getter) Non Evaporated Getter pumps have been chosen for the moment, though sheets of metal getters or cryopumps are also being considered. Strong magnetic shields have been installed to screen the large stray fields that could deflect the ion beam before it is neutralized and the residual component is safely dumped on a suitable target. A Montecarlo code simulating the beam from the last grid of the source (the grounded grid) to the plasma has been used to properly dimension the pumps and the magnetic shield [3]. The main issue in installing the beam on to RFX-mod is indeed the avoidance of beam stopping that might arise from re-ionization and prompt ion losses.

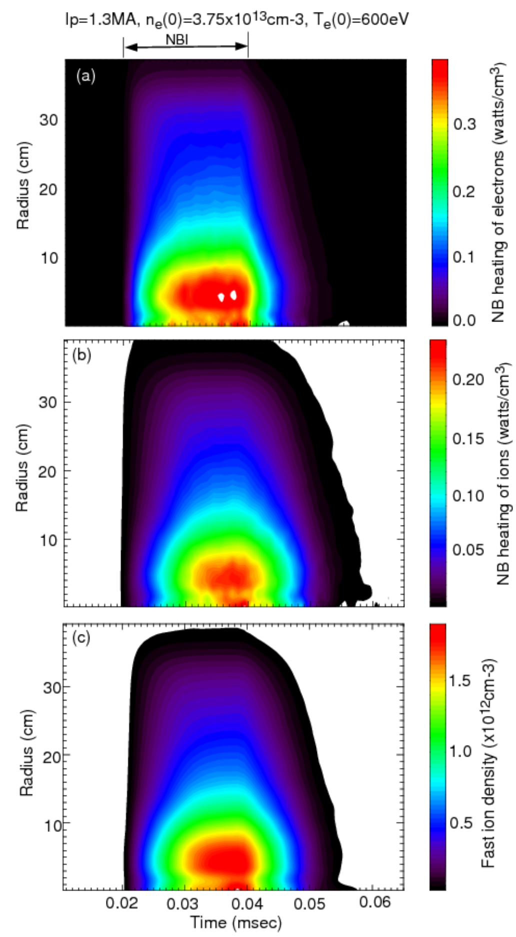

Fig. 2. *Simulation results of NBI injection to RFX-mod plasma using TRANSP code. Time evolutions and radial profiles of (a) power deposition on electrons, (b) power deposition on ions, and (c) fast ion density.*

3. Experimental plans

Topological constraints imply that the only acceptable injection geometry in RFX is radial and on the equatorial plane. As a matter of fact such geometry restricts the number of possible experiments to the study of the fast ion behavior in a RFP, since the amount of momentum that the beam can exchange with the plasma is very small. The overall heating effect is marginal due to the fact that the typical slowing down time of the fast ions (tens of ms) is long compared to the energy confinement time (several ms). Nonetheless, besides the widespread interest in the fusion community, fast ions confinement physics is particularly attractive in RFP's since it was shown that in the RFP fast ions feature confinement times [4] much longer than thermal ions. This has been ascribed to the appearance in the phase space populated by toroidally drifting fast ions of resonances (rational surfaces) not seen by thermal ions. Fast ions confinement should even improve in an RFP that has reached a helical equilibrium [5].

4. Simulation results

The injection of the AIST beam into RFX-mod has been simulated by the Monte-Carlo NUBEAM [6] module in the Tokamak TRANSP code [7] for a variety of RFX-mod experimental situations, in which fast ions are assumed to behave classically. After adapting plasma and equilibrium profiles to toroidal flux coordinate, required by TRANSP, only NBI in plasma without toroidal magnetic field reversal (F = $B_Z/<B_Z>$ =0) has been simulated. In Fig. 2, we show simulation results for an input of $T_e(0)$= 600 eV, $n_e(0)$= 3.75×10^{13} cm^{-3} and 20 ms beam pulse injected in the time window of t= 20-40 ms, in terms of power deposition on electron and ions and fast ion density. Heating occurs as expected first on electron and than on ions, though total heating of about 1 MW is marginal with respect to the typical input power in RFX-mod, which is of the order of 20 MW for the considered electron density. The fast ion density is the core could be as high as 5% of the electron density. As a consequence β of hot ions could be significantly higher than the thermal β, offering the possibility of studying Alfven instabilities.

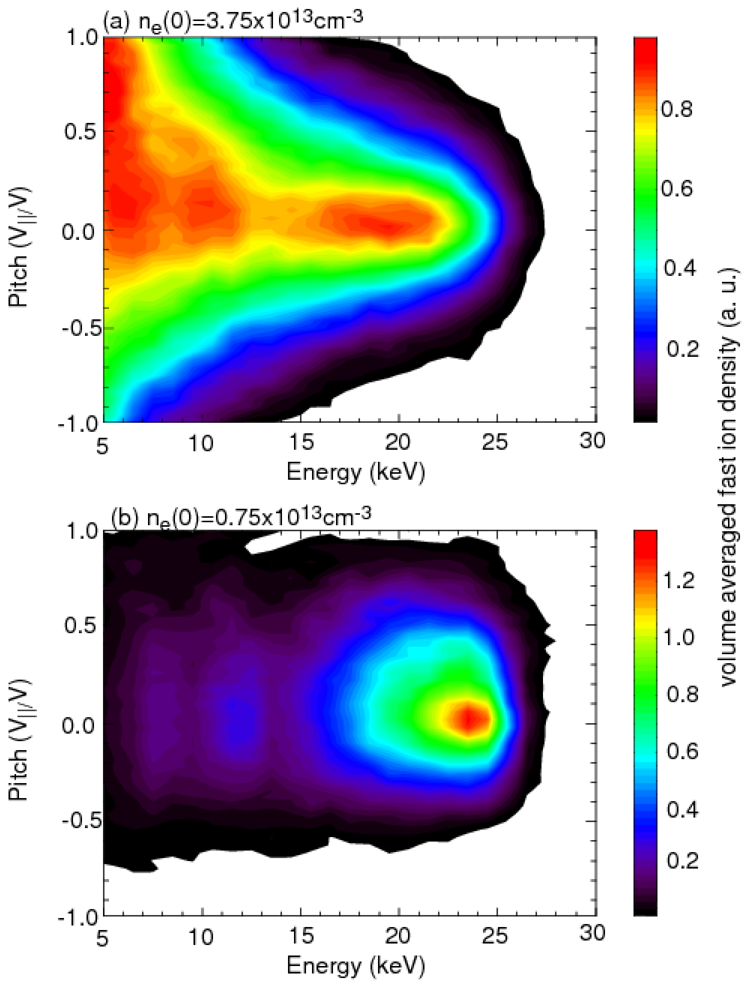

Fig. 3. Simulated volume averaged fast ion density profiles in phase space for two cases, (a) high density and (b) low density, at the same instant after beam injection.

TRANSP predicts that fast ions are mainly trapped particles with pitch ($V_{||}/V$) around 0. In the low density case ($n_e(0)= 0.75x10^{13}$ cm^{-3}), shown in Fig. 3(b), there is less pitch angle scattering and long fast-ion slowing down resulting in a larger fast-ion density than in the high density case ($n_e(0)= 3.75x10^{13}$ cm^{-3}), shown in Fig. 3(a).

In summary, the installation of a power neutral beam on RFX-mod with radial injection is expected to drive little net toroidal current, of the order of 5 A/cm^2, and negligible torque. Ion and electron heating appear to be marginal in general, while a significant fast ion population is expected to be generated, preferentially in the low density cases, thus allowing studies on fast ion confinement and Alfven instabilities.

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