Installation of the Multiaperture Negative Ion Source NIO1 and Related Studies on Negative Ion Sources and Beam Diagnostics


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INTRODUCTION

Negative ion sources [1-3] are a fundamental component of advanced Neutral Beam Injectors (NBI) [4-7], from which depend most of the outcome of the International Tokamak Experimental Reactor (ITER) project and which need to be strongly optimized in the perspective of the DEMO reactor [8]. A relatively compact radiofrequency (rf) ion source, named NIO1 (Negative Ion Optimization phase 1) [9-11], with 9 beam apertures for a total H- current of 130 mA at -60kV extraction voltage, is being tested and installed at Padua, in Consorzio RFX, to provide a test bench for source optimizations in the framework of the accompanying activities in support to the ITER NBI test facility. These activities enter also in the framework of INFN Group 5 experiments INFN-E (for Energy) and BEAM4FUSION, which also include development of neutron diagnostic for NBI injector prototypes as SPIDER and MITICA (under construction at Consorzio RFX [6,7]) and for tokamaks. This year, among theoretical researches related to negative ion sources, beam space compensation were substantially completed [12], and particular attention was dedicated to beam deflection cancellation [13,14] and critical revision of particle in cell simulation tools and beam optics [15,16].

NIO1 STATUS

NIO1 source magnetic configuration is a minimum B magnetic bottle, which requires placing hard ferrite magnets also behind the RF coil. Source is installed on a 2 m long diagnostic vacuum chamber, see Fig 1. There are three acceleration grids, named plasma grid (PG), extraction grid (EG) and post acceleration grid (PA), followed by a repeller electrode (REP) for a better control of the space charge compensation of the extracted beam. Accelerated H- can be dumped on calorimeter with 283 small sampling holes, and a segmented cooling circuit, see Fig 2. The critical cooling circuits of EG, PA and the calorimeter, aiming at sustaining a continuous beam power of 9 kW, were obtained with electro-deposition techniques. Numerous cooling channels for source magnet multipoles were carved in copper and closed by brazing. Major parts of the overall installation, including the 70 kV/ 50 kVA insulation transformer powering a high voltage deck and an optical cavity ring down spectrometer were prepared and separately tested. A 2.5 mm lead shield enclosing NIO1 source is being designed and acquired. The closed cooling circuit fluid is deionised water, with a heat exchanger to glicolated water and variable speed pump; major parts are acquired and installation will follow lead shield. Development of the Fast Emittance Scanner and preliminary tests of matching box at LNL were discussed previously [9]. Due to its relatively small size, NIO1 source seems well suited for 3D simulation studies [17].

NIO1 STATUS

SPACE CHARGE COMPENSATION

The propagation of H- (or D-) beams is subject to collisions with the background gas, whose presence along the beamline are due to losses from the plasma source and from the gas neutralizer. The secondary ions (typically H2+) so produced in the drift tube (after the accelerator column) are accumulated in the potential well induced by the beam space charge, influencing the local space charge distribution and the optics. Simple radial balance 1D modeling forecast a total compensation of the beam charge, which is clearly beneficial for beam transport. Our more refined 2D planar symmetric models and simulations both
with PIC and fluid codes, have shown that compensation is not effective for a length \( L_1 \) after the last accelerating grid PA, see Fig 3; moreover a current \( I_1 \) of \( H^+ \) ions is pulled back to the accelerating columns, and is detrimental for source efficiency. Both \( L_1 \) and \( I_1 \) may be reduced with a repeller grid REP (positive with respect to PA and placed just after PA), as implemented in NIO1.

**NEUTRON DIAGNOSTIC**

Passive neutron diagnostic can monitor the D ion impinging on SPIDER calorimeter [18,19], by reactions with previously implanted D whose density can be taken as saturated in first approximation; so distribution of the 2.45 MeV neutrons reflects beam intensity. The GEM (Gas electron multiplier) neutron detectors give a rapid response, and are simple and robust enough to be placed just on the back of SPIDER calorimeter. Diamond-based and optimized GEM-based detectors were shown to give comparable beam profiles in recent test experiments, with the obvious advantage of economy and large area coverage in favour of GEMs. A dedicated signal acquisition chip, capable of processing signal from 32 GEM channel is also under construction in the framework of BEAM4FUSION experiment.

Related applications of GEM detectors are: a) discrimination of 2.45 and 14 MeV neutrons, for fusion plasma diagnostic; b) epithermal neutron detection, with a Boron converter foil; c) monitoring of beam targets (SPES).

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