PRELIMINARY COMMISSIONING RESULTS OF THE PROTON SOURCE FOR ESS AT INFN-LNS

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Abstract

At Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS) - the commissioning of the high intensity Proton Source for the European Spallation Source (PS-ESS) is under way. Preliminary results of plasma diagnostics collected on a testbench called "Flexible Plasma Trap" (FPT) will be correlated to the peculiarities of the magnetic system design and of the microwave injection setup with a view of the possible implications on the beam extraction system. The status of the costruction is presented.

INJECTOR FOR THE ESS ACCELERATOR

The source named Proton Source for ESS (PS-ESS) (see Figure 1) was designed with a flexible magnetic system and a compact tetrode extraction system with the goal to minimize the emittance and the time needed for the maintenance operations. The ESS injector design has taken advantage of recent theoretical updates together with the new plasma diagnostics tools developed at INFN-LNS. The improved know-how will permit to fulfil the requirements of the ESS normal conducting front-end; the proton beam should be 74 mA which can be obtained with a total beam current of about 90 mA. The beam stability during the normal operations (in terms of current and emittance) shall be within ±3.5% as for pulse to pulse variation and ±2% of the beam current if averaged over a period of 50 us. The pulse duration is 2.86 ms with 14 Hz repetition rate. The requirements for the proton source and the LEBT are summarized in the Table 1. A detailed study of the beam transport in regime of space charge compensation was done and experimentally verified [1]. A reliability better than 95% is requested for the whole accelerator, thus meaning that the source reliability is expected to be greater than 99%.

Table 1: PS-ESS Requirements

Parameters	Value
Proton current range	60-74 mA
Proton fraction	>80%
Current stability (50 µs averaged)	±2 %
Pulse to pulse variation	±3.5%
Beam energy	70-80 ±0.1 keV
Repetition rate	1-14 Hz
Pulse length	5-2.860 ±1 µs
Current reduced using iris	2-74 ±1 mA
Restart after vacuum break	<32h
Restart after cold start	<16h
Emittance (99% normalized)	<2.25 π.mm.mrad
Twiss parameter α	1.02 ±20%
Twiss parameter β	0.11 ±10%
Beam pulse rise and fall time	<20 µs
LEBT pressure	<$6{\cdot}10^{-5}$ mbar

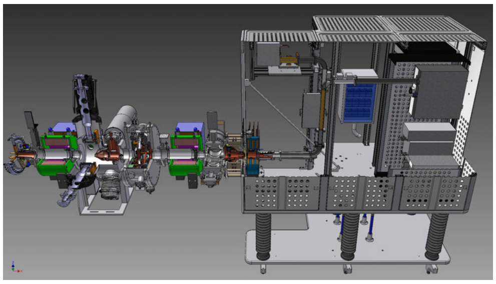

Figure 1: 3D rendering of PS-ESS, platform and LEBT.

FUNCTIONAL TESTS OF SUBSYSTEMS

Body Source and Microwave Line Status

The source design already described in previous papers [2] has been upgraded according to the new requirements. Figure 1 shows the general layout of the source, including the plasma chamber, the magnetic and extraction systems and the LEBT components. The racks containing the three power supplies for the magnetic system, the magnetron and the fast microwave shout down unit have been allocated on the installed platform. The fully assembled source including the insulating column and the extraction electrodes is shown in Fig. 2. The first LEBT element will house water and electrical connections for the HV repelling cable, two turbo molecular pumps and vacuum gauges, gas inlet and the residual gas analyzer. In Fig. 3 the microwave line it is shown: it consists of a magnetron 2 kW 2.45 GHz with continuous power supply on the filament to avoid ripple (around ±0.5% was measured), the Automating Tuning Unit and the waveguide branching (including the quartz microwave pressure window and the matching transformer).

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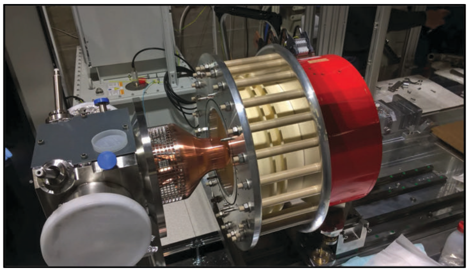

Figure 2: Source, extraction and first LEBT element.

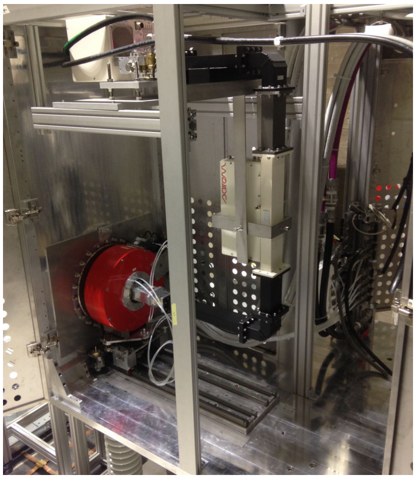

Figure 3: Microwave injection system

HV Power Supply, Insulating Transformer, Insulated Cooling Input and Grounding Mesh

Another subsystem that has been optimised is the source extraction. The design has included a detailed thermal characterization performed by COMSOL simulations. The extraction electrodes have been designed with the possibility to easily change their shapes: this makes the setup very versatile. The High Voltage power supply, 100 kV, 150 mA and the insulating transformer have already been installed (Fig. 4). Optionals requested to increase the stability and fulfill all ESS requirements have been: lower HV ripple ($<1{\cdot}10^{-5}$pp), higher voltage stability ($< \pm1 \cdot 10^{-5}$/8h). The dynamic behavior and the stability of the power Supply FUG HCH 15000-100000 MOD can be evaluated from Fig 5 which meets the ESS requirements.

Figure 4: HV power supply and insulating transformer

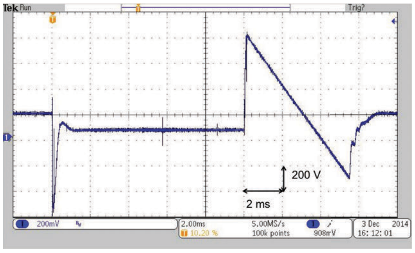

Figure 5: Voltage fluctuation due to the change of the load applied to the power supply; Pulse load of 100 mA, 10 ms, 14 Hz)

The Recovery time for ON transition, the Drop voltage, the Recovery time for OFF transition and the Ripple (very low: 2.5 V < 10 V) satisfy all the requirements by properly selecting the stable part of the pulse through the chopper and by leaving out the sparks due to the large “no load /full load” variation. The insulation of the extraction column and the vacuum tightness have been successfully verified through HV and vacuum leak tests. The extraction column (at operating pressure of $6{\cdot}10^{-6}$ mbar) has been tested without any sparks at 90 kV for 1h e 30’ at 19.2 °C e 38% humidity level. These very good results have been obtained well above the nominal operating voltage that will be 75 kV.

Moreover the ground mesh has been installed in order to reduce the damaging risk on the control electronic caused by eventual sparks.

LEBT Components Status

The iris has been mechanically commissioned at LNS and it successfully passed the vacuum test (Fig. 6). The solenoids with integrated steerers inside have been delivered to LNS, Catania where there are already two solenoid pipes with gas injection and bellow. Similar steerers as the IFMIF ones have been upgraded to increase the magnetic field uniformity.

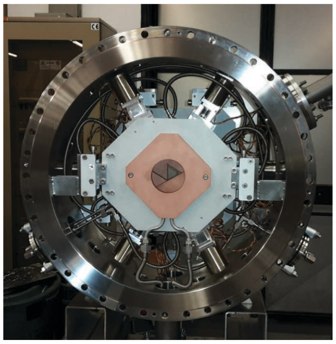

Figure 6: Iris (length=300 mm, beam aperture from 1 mm to 80 mm with hexagonal shape) of the LEBT used for selecting different portions of the beam.

The chopper design was improved after the experience gained during the test of the old chopper tested at CEA. The collimator designed was almost finished in accordance with the requirements of Beam Diagnostics and Vacuum groups and CEA RFQ people.

PLASMA DIAGNOSTICS TESTS

Both the proton current and the emittance of ESS proton beam depends on the energy distribution functions of ions and electrons. Therefore, the knowledge of the plasma parameters is a key factor for the optimization of the ESS source. Preliminary tests of plasma diagnostics are being carried out on the Flexible Plasma Trap (FPT), a testbench designed for studies of plasma diagnostics to apply to the ESS ion source which permit to replicate the PS-ESS magnetic trap; it is constituted by 3 copper coils, allowing magnetic field profile changes in a very flexible way (from off-resonance configurations to simple mirror or magnetic beach). Microwave frequency of FPT is also tunable, for testing higher density plasma regimes. Preliminary studies on the electron density distribution have been carried out by means of invasive and non-invasive diagnostics. A movable Langmuir Probe (LP) permits the characterization of plasma parameters. Figure 7 shows the electron density calculated for different LP positions, for microwave powers ranging from 10 to 60 W in B_{min} configuration. The figure puts in evidence how plasma is confined between the ECR layer for any value of microwave power. The ion confinement optimisation requires a complete control of cold electrons displacement, which can be performed by optical emission spectroscopy (OES), able to achieve non-invasive measurement of the low energy (<10 eV) electron population. Preliminary measurements of OES have been carried out by the ImSpector V8E spectrometer. This instrument covers the wavelength range 400-1000 nm, with a dispersion of 65 nm/mm and 2 nm spectral resolution. The spectrometer has been calibrated with a Hg-Ar and tested in a Argon plasma. Figure 8 shows the spectrum of the Argon plasma obtained in B-minimum magnetic configuration, at 20 and 100 W microwave power. Plasma parameters can obtained by means of the line ratio method (see ref. [3]). In case of Argon, plasma density is calculated by the ratio between 480 nm and 488 nm line, highlighted in figure 8. X-ray spectroscopy represents also a very important tool for the non-invasive characterization of the warm and hot electron population. "Volume-integrated" X-ray spectroscopy is performed by using a silicon drift detector (2-30 keV electron energy domain) and a hyperpure germanium (>30 keV electron energy domain). Spatially resolved spectral distribution of X-rays is obtained by using a so called "pin-hole camera", i.e. a CCD camera sensitive in the X- ray domain coupled to a pin-hole. X-ray diagnostics have been already developed used for the determination of plasma parameters, as shown in reference [4].

TESTBENCH AND NEXT STEPS

All the work for the site commissioning has been completed including the grounding, the shielded cabinets, lead wall (see Figure 9). Installation of vacuum equipments will be done soon, along with water cooling system and some electric power distribution. The first plasma is expected for June 2016, while beam diagnostics will be available in summer 2016 when the beam characterization will begin.

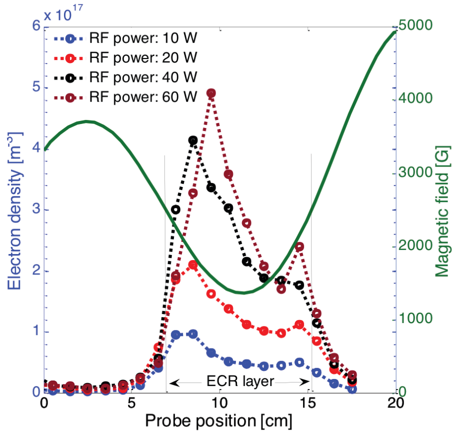

Figure 7: Electron density obtained by LP as a function of LP position and RF power.

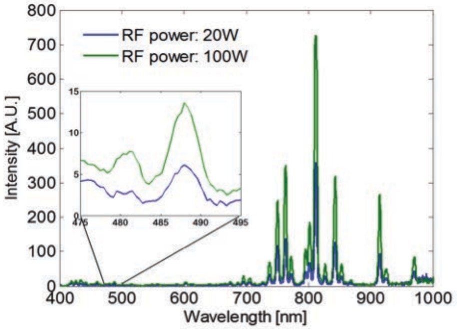

Figure 8: View of an Argon spectrum in the 400-1000 nm domain. Plasma density can be obtained by the line ratio 480/488.

Figure 9: Site preparation at INFN-LNS.

ACKNOWLEDGEMENT

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