

COMMISSIONING OF THE HIGH INTENSITY PROTON SOURCE DEVELOPED AT INFN-LNS FOR THE EUROPEAN SPALLATION SOURCE

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Abstract

At the 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) started some weeks ago. Beam stability at high current intensity is one of the most important parameter for the first steps of the ongoing commissioning. Commissioning plan and preliminary characterization are also presented, with the aim to satisfy the requirement above.

DESCRIPTION

The design of PS-ESS and LEBT involved many efforts from different institutions with the aim to get a source highly reliable and satisfying the ESS requirements. The mechanical and functional interfaces between the different groups of INFN-LNS, ESS and CEA-IRFU were properly addressed and the layout shown in the Figure 1 is now complete. All details are finalized, most of the elements have been already delivered and few other parts are under construction. The source is equipped with a flexible magnetic system consisting of three coils independently energised [1]. The plasma chamber is coupled with a matching transformer to optimize the microwave matching and enhance the electric field on plasma chamber axis. The entire source body is supported with a double pin joint to permit a higher degree of freedom both during alignment and maintenance procedures. The insulating column is made with a single alumina gap. The external surface has an innovative design

that permit to reduce the electric field up to 6.5 kV/cm. The so called “triple point” (i.e.: the junction between the alumina the metal and the vacuum) been designed to achieve an electric field lower than 5.5 kV/cm taking into account our previous experiences. Inside this element the tetrode extraction system is placed. It is composed by the plasma electrode located at the exit of the plasma chamber, and a set of three electrodes supported by the first element of the LEBT. There are two grounded electrodes and one repeller electrode in the middle of them. All the electrodes are water cooled. The first element of the LEBT houses two turbo molecular pumps (TMP), water and electrical utilities for the extraction system, a Residual Gas Analyzer (RGA), three different type of vacuum gauges, a burst disk and the gas injection needed to improve the space charge compensation of the LEBT. The design of this part was focused to be as compact as possible [2]. This element is the most important part for the alignment of the entire source. The beam will be then transported through the 2.4 m long LEBT with two solenoids; magnetic steerers are hidden inside each solenoid to reduce the total length of the LEBT [3]. The two LEBT solenoids are identical as well. A bellows and a gas injection are integrated in their design. Both pipes are followed by a gate valve that will permit maintenance operations without breaking the vacuum. The Iris is a six blade diaphragm that will be used to reduce the beam current injected inside the following part of the accelerator (Radio Frequency Quadrupole, RFQ) without changing the source conditions.

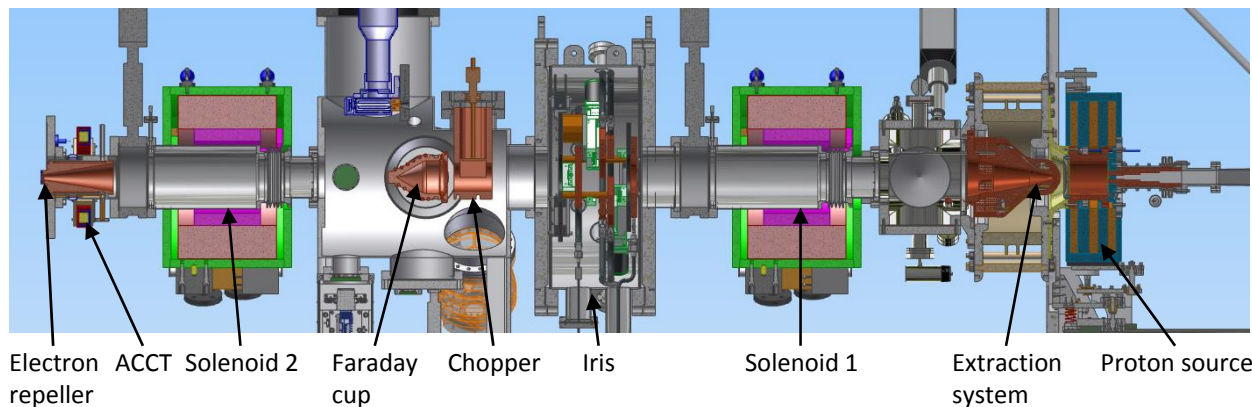


Figure 1: Experimental setup of PS-ESS with the relative LEBT.

This will permit to achieve stable working conditions of the source for a wide proton current range (6-74 mA) allowing a safe start-up of the accelerator when the beam transport is checked with reduced power. The diagnostic box is the core of LEBT where the beam will be continuously monitored during operating conditions; it houses two Emittance Measurement Units (EMU), one Doppler Shift Measurement (DSM), a Faraday Cup (FC), a Non-invasive Profile Measurement (NPM), the chopper, two TMPs, three vacuum gauges and a burst disk. The chopper deflects and defocus the beam out of the LEBT collimator hole to speed up the rise and fall time of the beam pulse injected into the RFQ. The LEBT collimator works as a beam dump for the beam when it is deflected by the chopper and for the H₂ beam, moreover it is necessary to reduce the conductance between the LEBT and the RFQ because of different working pressure regimes. In fact, the LEBT may work up to $4 \cdot 10^{-5}$ mbar while the pressure in the RFQ has to be kept under $1 \cdot 10^{-7}$ mbar. In this element a repeller electrode to avoid the transmission of free LEBT electron to the RFQ and a beam current transformer to measure the beam current injected in the RFQ are also integrated. Finally, for the source commissioning at INFN-LNS, a diagnostic tank with the same characteristics of the LEBT diagnostic tank will be placed after the LEBT collimator.

FIRST SUBSYSTEM COMMISSIONING

Before to start the beam commissioning it has been necessary to test the functionality of all the ancillary equipment. The cooling system was tested for both the circuit at ground and in the high voltage platform. The temperature of sensitive devices was checked with power over the standard needed for this type of source and also for different plasma heating power. The microwave matching has been also tested with high accuracy for different operating conditions with a double-arm and high directivity directional coupler for an accurate measure and the forward and the reflected power. The control and safety systems were designed and tested in order to provide the highest security and the highest detailed description of all issue events.

Vacuum System Flexibility Test

The residual gas pressure in the LEBT and the species composition are important parameters for the operation of the proton injector as they affect the space charge compensation of the LEBT. Therefore, it has been decided to study the operations with the same pressure but with different gas fluxes by changing the speed of the turbo pumps. Figure 2 shows the pressure measured in the first part of the LEBT for different value of gas flux inserted in the plasma chamber. There are two linear trends, one with the use of only one pump and the other with two pumps. The degree of freedom in the vacuum system will permit to increase the comprehension of the combined effect of pressure and gas flux on the plasma chamber.

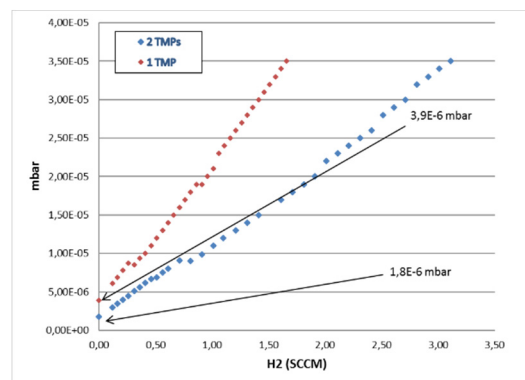


Figure 2: Characterization of the vacuum system to prepare source test at various pressures and at various gas fluxes.

COMMISSIONING PLAN AND PERSPECTIVES

The commissioning of the PS-ESS and low energy beam transport (LEBT) (shown in Figure 1) will start in October 2016 and will end in September 2017. It is limited on one hand by a tight time schedule, and on the other by the number of requirements that need to be fulfilled [1]. The scope of the commissioning is to have a characterized beam at the LEBT-RFQ lattice interface in advance of the ready-for-installation (RFI) date at ESS (2017-11-02).

The commissioning consists of four phases: (1) start-up and beam current measurements after the ion source, (2) beam characterization after the ion source, (3) beam characterization after the first solenoid, and (4) beam characterization at the LEBT-RFQ lattice interface. The first two phases use a cross-piece at the location of the first solenoid to house the diagnostics. Phase 3 measures the beam in a diagnostics tank placed after the iris, and Phase 4 uses a dedicated commissioning tank to measure the beam at the RFQ input. Table 1 summarizes the four commissioning phases with the main tasks to be performed, and the available diagnostics.

Due to some delays, we are working on a mitigation plan to extend the commissioning at INFN-LNS with a second proton source and LEBT. The main idea is to deliver the different subsystems forming the source and LEBT well before the planned date (named RFI date) and deliver only the source body commissioned at INFN-LNS just before the RFI date. In this way, the accelerator installation at ESS will not be delayed by a late arriving proton source and LEBT. The commissioning will then be concluded at INFN-LNS with a study of the long-term effects on the proton source, and optimization of the complete system.

Phase 1 & 2: Proton Source Characterization

The first two commissioning phases characterize the beam at the proton source exit. The instrumentation that will be used are: Faraday cup (FC), Doppler shift monitor (DSM) and beam stopper. The transition to Phase 2 is defined by installing an emittance measurement unit (EMU), scheduled to arrive in November 2016.

Phase 1 focuses on optimizing the proton source plasma. The magnetic field of the three solenoids surrounding the plasma chamber will be tuned and properly matched to the 2.45 GHz microwave. The hydrogen gas injection system will also be optimized accordingly to obtain a stable beam with a high proton fraction.

Phase 2 characterizes the 3 ms, 14 Hz proton beam at the PS-LEBT lattice interface. The parameters that will be studied are primarily: the beam current (max. > 90 mA, nom. 74 mA), the flat top stability ($\pm 2\%$), the pulse-to-pulse stability ($\pm 3.5\%$), the proton fraction (> 75%), the normalized transverse emittance ($1.8 \pi \text{ mm.mrad}$, 99%), and the beam divergence (80 mrad, 99%).

Phase 3&4: LEBT Characterization

The last two phases study the beam transport through the LEBT and the matching of the proton beam emittance to the RFQ input. Phase 3 studies the transport through the first solenoid with integrated horizontal and vertical steerers, the beam current reduction by the iris, and the space charge compensation effect by gas injection (H_2 , or N_2). Phase 4 is the final stage of the commissioning and studies the beam transport through the complete two-solenoid LEBT to produce a matched beam to the RFQ.

Perspectives

The degrees of freedom present in the design of the different subsystem of the high intensity proton source and its relative LEBT will play a fundamental role in the source commissioning to find the optimum setup that will be able to satisfy ESS requirements. Moreover, the design efforts have been focused to reduce the time needed for the maintenance procedures and to maximize the source reliability, with the aim to increase the overall accelerator availability. The high level user interface was designed not only to be a friendly interface for the final use but also provide additional functionalities that will help in the parametrized study of the source and of the LEBT. The experience already gained from our group in the installation and the relative commissioning of similar sources in other places (i.e.: VIS transported at Vancouver as intense H_2^+ injector) will help us to define the tasks and to optimize the work needed for the installation and commissioning in Lund.

ACKNOWLEDGEMENTS

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Table 1: The four phases of the commissioning with the allocated time, available diagnostics, and main tasks. FC: Faraday cup, DSM: Doppler shift monitor, EMU: emittance measurement unit, NPM: non-invasive profile monitor, ACCT: ac (beam) current transformer.

Phase	Date	Diagnostics	Main tasks
1	Oct. - Nov. 2016	FC, DSM	Extract first beam, configure the three coil magnetic system, match the RF with the magnetic field, and optimize the gas flux and pressure.
2	Nov. 2016 - Mar. 2017	FC, DSM, EMU	Measure and optimize the beam current, emittance, and proton fraction. Optimize the plasma conditions, and the matching to the beam extraction system.
3	Apr. - Jun. 2017	FC, DSM, EMU, NPM	Study the effect of the iris, the magnetic field of the first solenoid, and the first steerer. Optimize gas injection in the LEBT for space charge compensation.
4	Jul. - Sep. 2017	FC, DSM, EMU, NPM, ACCT	Study the effect of the two solenoids and steerers, the chopper, and the collimator repeller voltage. Optimize gas injection for space charge compensation at two locations in the LEBT.

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