THE PROTON SOURCE FOR THE EUROPEAN SPALLATION SOURCE (PS-ESS): INSTALLATION AND COMMISSIONING AT INFN-LNS

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Abstract

A 2.45 GHz – 0.1 T microwave discharge Proton Source has been designed and assembled at INFN-LNS for the European Spallation Source (PS-ESS) in order to produce pulsed beams of protons up to 74 mA nominal current, at 75 keV of energy, with a transverse emittance containing 99 % of the nominal proton current below 2.25 π mm mrad and a beam stability of ± 2 %. The challenging performances of the machine have triggered specific studies on the maximization of the proton fraction inside the plasma and of the overall plasma density, including dedicated modelling of the wave-to-plasma interaction and ionization processes. The plasma conditioning phase started in July and excellent RF to plasma coupling, more than 99.5% is evident since the beginning. Reflected power fluctuation less than 0.05 % was measured providing a great starting point to reach the beam stability requested by the ESS accelerator.

INTRODUCTION

The European Spallation Source will be one of the most advanced technological tools for scientific and industrial development in Europe in the next decades. A linear accelerator is going to be built for the production of 2 GeV protons to be used for neutron production via nuclear spallation. Peak beam power will be 125 MW. Neutrons will be finally used for fundamental science and applied research.

The source named Proton Source for ESS (PS-ESS) [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. Figure 1 shows a picture of the High Voltage (HV) platform fully assembled with the source body and magnetic system, the microwave injection line, all power supplies, control system devices, cooling system, gas injection and measurement devices. 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 Table 1 and Table 2.

A detailed study of the beam transport in regime of space charge compensation was done and experimentally verified [2, 3, 4]. A reliability better than 95% is requested for the whole accelerator, thus meaning that the source reliability is expected to be greater than 99%. For that reason, the mechanical design was driven also to maximize the MTBF and minimize the MTTR.

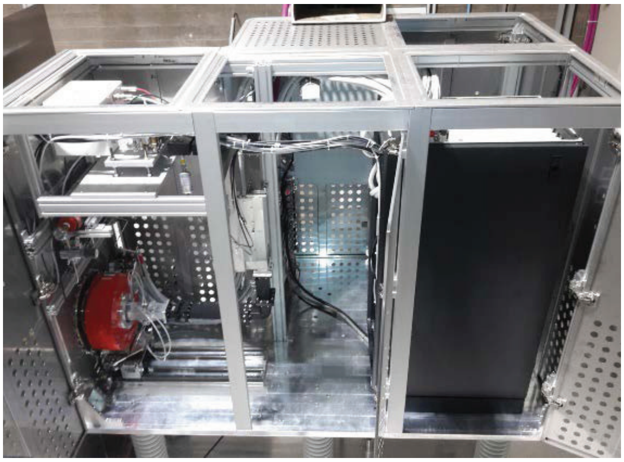

Figure 1: PS-ESS, high voltage platform detail.

Table 1: PS-ESS Requirements

Parameters	Value
Proton current range	67 – 74 mA
Proton fraction	> 75 %
Current stability (50us avr.)	± 2 %
Pulse to pulse stability	± 3.5 %
Beam energy	70 – 80 ± 0.01 keV
Repetition rate	1 – 14 Hz
Pulse length	5 – 2860 ± 1 us
Current reduced (with iris)	2 – 74 ± 1 mA
Restart after vacuum break	< 32 h
Restart after cold start	< 16 h

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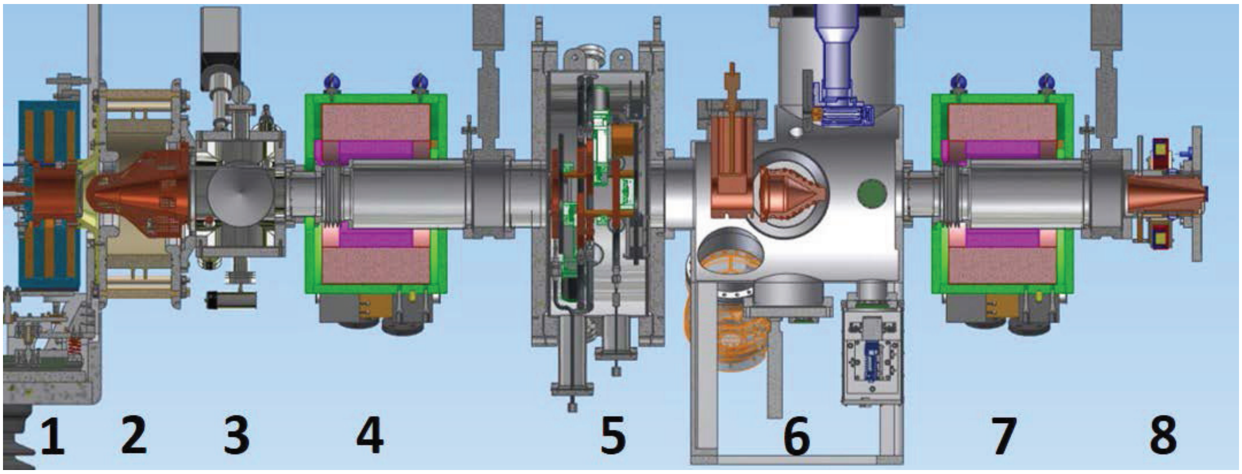

Figure 2: PS-ESS and LEBT layout.

Table 2: LEBT Requirements

Parameters	Value
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 us
Gas type	≤ 28 g/mol
Pressure	$< 6 \cdot 10^{-5}$ mbar

PS-ESS AND LEBT LAYOUT

Figure 2 shows the PS-ESS and LEBT layout that today is arrived to a final stage. Every details are finalized, most of the element was already delivered to Catania and the other part are under fabrication in different manufacturing companies.

Description of the layout will follow the notation inserted in the Figure 3:

1. Plasma chamber with flexible three coils magnetic system, matching transformer for optimized microwave to plasma coupling and double pin joint support for the free alignment of this part to the first element of the LEBT
2. Insulating column made with a single alumina piece. The external surface has an innovative design that permit to reduce the electric field up to 6.5 kV/cm. The shape around the junction between the alumina the metal and the vacuum, commonly named triple point, was completely redesigned to achieve an electric field lower than 5.5 kV/cm in correspondence of the ground side. Inside this element the tetrode extraction system can be seen. It is composed by the plasma electrode located in the plasma chamber wall, and a set of three electrodes supported by the first element of the LEBT. There are two grounded electrodes and one repeller electrode that will avoid to inject free electrons from the LEBT to the plasma chamber. All three electrodes are water cooled.
3. The first element of the LEBT house 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. This element is the most important peace for the alignment of the entire machine.
4. First LEBT solenoid with two magnetic steerers inside to reduce the total length of the LEBT. The two solenoids are identical.
5. 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 change the condition of the source. This was designed to use the most stable working condition of the source even during the start-up of the accelerator when the beam transport is checked with reduced power.
6. The diagnostic box will house two Emittance Measurement Units (EMU), one Doppler Shift Measurement (DSM), a Faraday Cup (FC), a Non-invasive Profile Measurement (NPM), two TMP, three vacuum gauges and a burst disk. Inside this part that was designed by the ESS beam diagnostic group there is also housed a chopper designed by INFN-LNS, it will deflect and defocus the beam out from the LEBT collimator (part 8) hole to speed up the rise and fall time of the beam pulse injected into the RFQ.
7. The two LEBT solenoid are identical as well are identical the two beam pipes that are inside. A bellow and a gas injection is integrated in their design. Both pipes are followed by a gate valve that will permit maintenance operations without break the vacuum where is not needed.
8. Two are the main function of the LEBT collimator, the first is to work as a beam dump for the for proton beam when it is deflected by the chopper electric field and for the H_2 beam. The latter scope is a vacuum break between the LEBT that can work with a pressure up to $6 \cdot 10^{-5}$ mbar and the RFQ that need to work under $1 \cdot 10^{-7}$ mbar. Additionally, in this element there are also

integrated a repeller electrode that avoid the transmission of free LEBT electron to the RFQ and a beam current transformer that measure the beam current injected in the RFQ.

9. In the ESS accelerator layout, after the LEBT collimator will be the RFQ, while during the commissioning in Catania will be a diagnostic tank with the same characteristics of the LEBT diagnostic tank.

The source is actually fully assembled (Figure 1) while only the first part of the LEBT is actually assembled (Figure 3) and ready for the first two commissioning phases. This setup is able to house one FC, one DSM, one EMU and a beam stop. The first phase will be the characterization of the current produced by the source using the FC and the DSM. In November the EMU delivery is planned and the emittance of the beam produced by the source will be characterized for different source parameters configuration.

Figure 3: LEBT configuration for the first two beam commissioning phases.

FIRST PLASMA CONDITIONING RESULTS

Plasma conditioning is the first operation that must be done after the assembly of a new source. It consists in the gradually turn on of the RF power to slowly increase the plasma density. The plasma is cheeped for different hours and for different times it is switched on and off. It is needed to clean the plasma chamber walls using the plasma sputtering and heating. Even if it is only a cleaning procedure we tried to used it also as a test to evaluate the goodness of some technical choices.

The three coils magnetic system of PS-ESS was designed to be a very flexible system. By using the same code used for the design of the magnetic system, COMSOL Multiphysics, we are able to choose a magnetic field profile and obtain, as an output, how to energise the three coils to be as close as possible to the request. The code provide also how much the obtained profile differs from the requested. Figure 4 is an example of how much precise can be the definition of the magnetic field profile. We requested a flat field of 900 G inside the plasma chamber and the ECR resonance (875 G) at the injection side of the plasma chamber wall. This is the most common magnetic field profile used for the Microwave Discharge Ion Source (MDIS) and with this profile we observed an excellent behaviour since the beginning. During the commissioning of the source we will have the time to test different magnetic profiles in a very easy way.

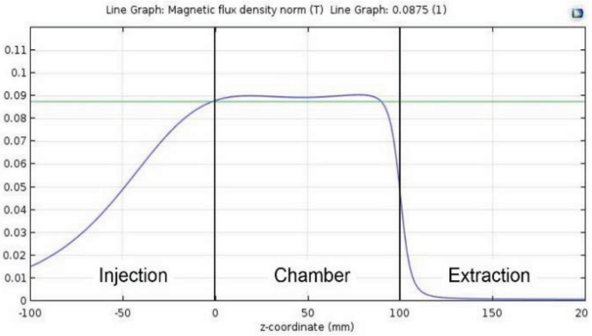

Figure 4: On axis magnetic field profile used during the plasma chamber conditioning.

The PS-ESS microwave injection line is composed by the magnetron head that produce the microwave, an Automatic Tuning Unit (ATU) that work as impedance matching between the wave guide and the plasma chamber, a directional coupler where two probes are connected to measure the forward and the reflected microwave power, the matching transformer and the plasma chamber. The data acquired with the two RF probes shows that the design is correct and an optimum match of power inside the plasma chamber is reached. Figure 5 shows that plasma ability to adsorb incoming microwave power increase gradually from 20 W to 120 W. After this value the plasma density is enough to adsorb more that 99.5 % of the injected power. This behaviour is promising for the future.

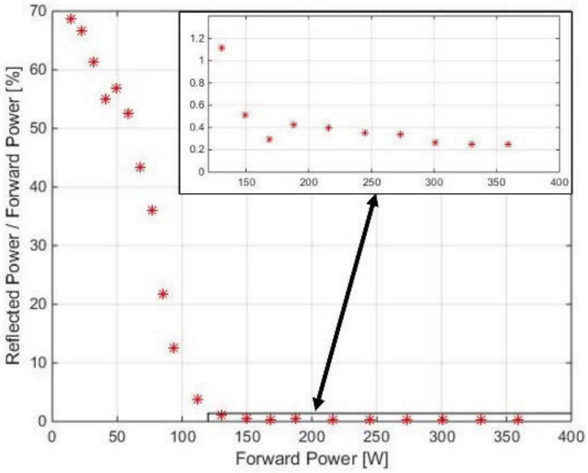

Figure 5: Fraction of reflected microwave power vs injected.

The software used for the data acquisition of the RF probes gives us also the possibility to extract the stability of the two measured power values. We select a data acquisition length of 10 us and an acquisition rate of 10 Hz, after 2000 of counts the standard deviation was calculated. Figure 6 shows the fraction between the standard deviation and the adsorbed power (forward minus reflected) versus the forward power. The result shows that with an injected power greater that 120 W the plasma sows a very stable condition with a fluctuation less than 0.05 %. This is a fundamental parameter that will help to reach the ± 2 % of beam stability requested by ESS.

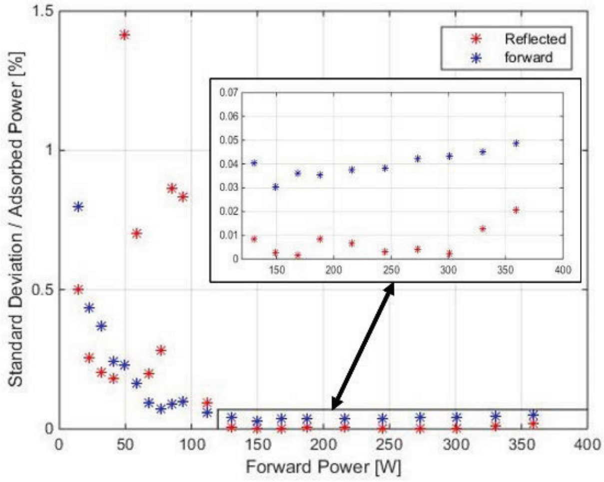

Figure 6: Stability of microwave absorbed power.

CONCLUSION

The design of PS-ESS and the LEBT is completed, the manufacturing of all components is almost completed and the installation is ready for the first beam commissioning. The first plasma conditioning stage produces comfortable result that confirm the technical choses inserted in the design of the microwave injection line. The stability of the microwave power adsorbed by the plasma, greater than 99.95 %, is a promising result that will work to obtain the beam stability requested by ESS. Everything seems going in the right direction and we are confident for reach the performance requested by the ESS accelerator.

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