ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPORI19

HSMDIS PERFORMANCE ON THE ESS ION SOURCE

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Abstract

The ESS ion source, developed at INFN-LNS and installed at the ESS facility, is fully working and in operation for the linac beam commissioning. The commissioning of the source was done in Catania and in Lund showing high reproducibility related to the beam diagnostic parameters that can be measured with the subset of equipment currently available in Lund. The analysis of the data collected during the commissioning in Catania discloses the possibility to use a new source configuration named High Stability Microwave Discharge Ion Source (HSMDIS), able to improve beam stability and lower beam emittance. This paper shows the capability to increase the beam current intensity, with preserving beam stability, by changing only the microwave power. Linearity was tested from 10 to 120 mA of the total extracted beam current. In addition to the nominal beam current, we can provide the lower values needed for the different phases of the accelerator commissioning and higher values for future accelerator development. The source stability is evaluated through intra-pulse stability and pulse-to-pulse stability.

INTRODUCTION

The project to build and commission the ESS accelerator to provide user beam in 2025 is progressing well. In particular, the Normal Conducting Linac (NCL) has been installed, RF conditioned and commissioned with full peak current beam up to the first DTL tank. A shutdown period has now started to allow the installation of three additional DTL tanks and a Faraday cup. RF conditioning activities of tanks 2, 3 and 4 will begin in early 2023 and further beam commissioning soon after. At the end of that phase, the temporary shielding wall in the tunnel will be removed to allow the installation of DTL5 and connection to the Super-Conducting Linac.

High Stability Microwave Discharge Ion Source

The commissioning of the high-intensity Proton Source [1, 2] developed by INFN-LNS, as an Italian In-kind contribution to the construction of the European Spallation Source, named PS-ESS [3], was accomplished at LNS in Catania [4-6]. Besides verifying the satisfaction of all ESS [7] accelerator beam requirements, a new magnetic field configuration [8] was discovered to be able to produce higher stability and lower beam emittance compared to the standard MDIS magnetic configuration. One of the key features that enabled the discovery was the development of a high-level control system [9] that make us able to test several thousands of source configurations. Our group is active in plasma and ECR ion source simulation since 2010 [10, 11]. Preliminary plasma simulations published in [8], and further ongoing simulations, show that the plasma heating schema and plasma dynamics change drastically between standard MDIS magnetic configuration and new one. For those reasons, we named this new mode of operation High Stability Microwave Discharge Ion Source (HSMDIS).

BEAM CURRENT CONTROL

Several sets of beam parameters, called beam modes, are defined to be used during the beam commissioning and general tuning of the ESS linac. These modes consist of various combination of beam current, pulse length and repetition rate to limit beam power for different stages of operation.

The probe mode is the lowest power beam, mainly for initial checks of the system and hardware and beam threading, the process to correct the trajectory and deliver the beam to the designated beam stop. In this mode, peak beam current must be reduced to 6 mA.

Six Blade Iris

After the first LEBT [12] solenoid, a six-blade movable collimator, named "iris", was inserted to be able to reduce the amount of transmitted current. The mechanics and the control system enable the choice of the hole aperture diameter from 6 mm to 75 mm. It is also possible to change the relative position of the aperture with respect LEBT geometrical axis, in a few millimetres range, depending on the selected aperture size. The transmitted beam is measured by a Faraday cup located in the diagnostic tank. The beam intensity modulation measurement, done at ESS and shown in Fig. 1, revealed that the transmitted beam did not preserve the pulse shape of the beam coming out from the source. For the largest and the smallest diameters, the flatness of the flat-top beam pulse satisfies ESS accelerator requirements, while for most of the aperture sizes the beam pulse shows a decreasing trend. This can be ascribed to an accumulation of secondary electrons generated by the beam stopped by the iris blades. This additional space charge changes the beam space charge compensation configuration and produces a reduction of the transmitted beam proportional to the accumulated distortion. There can be a second hypothesis that can explain the observed behaviour, but the time-dependent emittance measurement performed during the LNS commissioning proves that cannot be ascribed to the observed phenomena. If the radial density distribution of the beam change during the pulse duration, we can have a non-flat time behaviour selecting only the beam inside a certain radius. Time-resolve emittance measurement showed that after one millisecond the

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beam converged to a fixed configuration that preserves emittance and radial distribution for all the pulse duration.

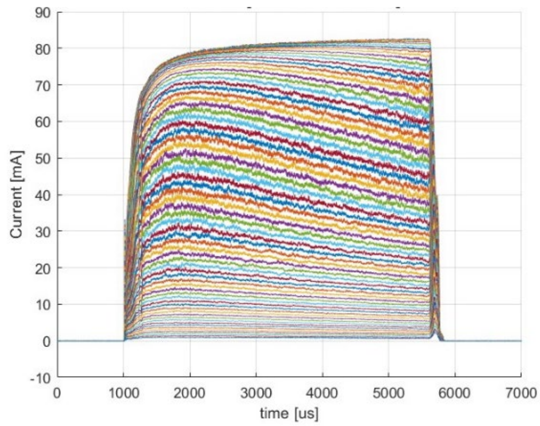

Figure 1: Beam current modulation using different iris aperture diameters, from 6 mm to 75 mm.

Beam Optic

Beam current modulation using different energization of the first LEBT solenoid is shown in Fig. 2. By reducing the focusing force of the solenoid, part of the beam remains in a certain diameter that can be focused by the second solenoid and then transmitted to the RFQ, while the external part of the original beam is not focused and be lost in the walls of the LEBT. The diameter size that can be focused by the second solenoid is approximately the same as the Faraday cup aperture and so can be measured by this device. Using this experimental setup same trend was observed with respect previous experiment. The variation of the decreasing slope versus the amount of the transmitted current is the same as in the previous experiment. The beam fraction which is not focused by the first solenoid hit the walls of the LEBT producing the same amount of secondary electrons as in the previous setup. Regardless of the phenomena that produce secondary electrons, we observe a change in the beam optics within a time frame of the order of milliseconds.

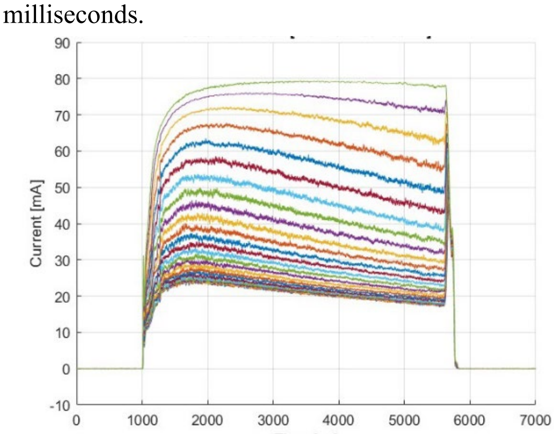

Figure 2: Beam current modulation using different energization of the first solenoid, from 0 A to 250 A.

Chopper

The chopper [13] is housed the diagnostic tank, it can apply a strong electric field that deflects the beam outside of the collimator hole located at the end of the LEBT. In the collimator, there is a conical part that can sustain the heating power of the stopped beam. The powering electronics and the stray capacitance were designed to achieve the electrostatic energization transition in less than a hundred nanoseconds. The beam optics transition, including the space charge configuration transition, takes a few hundred nanoseconds [13]. With this device, it is possible to select a temporal fraction of the produced beam pulse. This device is turned on to stop the beam while is switched off to let the beam passing. Perturbation of space charge compensation configuration, induced by electrons produced by the beam lost in the collimator, act only during the time the chopper is on and the beam is not passing through the collimator hole. Electrostatic modification of the space charge configuration induced by the chopper electrode polarized up to 11 kV is active only during the beam deflection. No space charge modification is introduced by this device when the beam is sent to the accelerator because is electronically switched off and the mechanical part do not interact with the beam. It is possible select beam intervals from few microseconds to few milliseconds (shown in Fig. 3B).

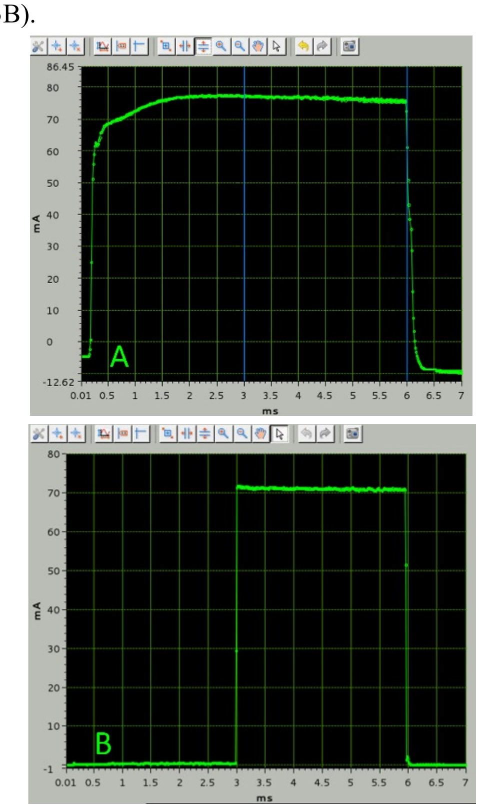

Figure 3: A) beam pulse produced by the source; B) chopped beam pulse at the end of the LEBT.

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Microwave Power

The HSMDIS configuration is extremely interesting also because it is extremely easy to change the amount of current produced by the source. With this magnetic configuration, the amount of produced beam is proportional to the amount of RF power injected into the plasma chamber. Beam pulse shapes for different microwave powers are shown in Fig. 4 where it is possible to see the flatness of the pulse shape produced. The intra-pulse stability requirement is satisfied for the entire range of pulse amplitude shown.

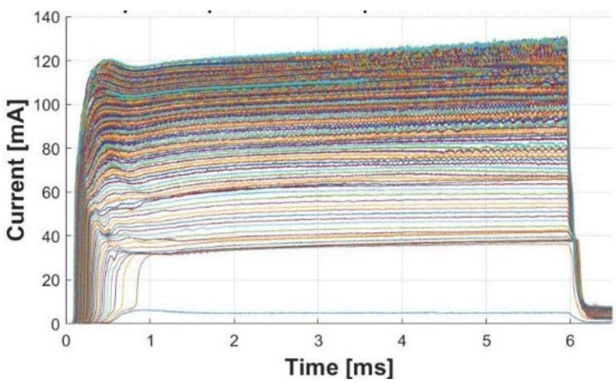

Figure 4: Beam current modulation using different microwave power injected in the plasma chamber, from 100 W to 1200 W.

The pulse-to-pulse stability ESS accelerator requirement, shown in Fig. 5, is also satisfied for tens of hours without any source configuration change. The trend shown is collected from the turn-on of the source, for forty hours, it shows a fast intensity change in the few minutes of operation due to the temperature increase of the plasma chamber. Then a slowly decreasing trend is observed. After more than thirty hours from the ignition, a small increase in the microwave power was done to compensate for the decreasing trend. This is an example on how easy and effective the beam intensity modulation is performed by changing the injected microwave power in the source.

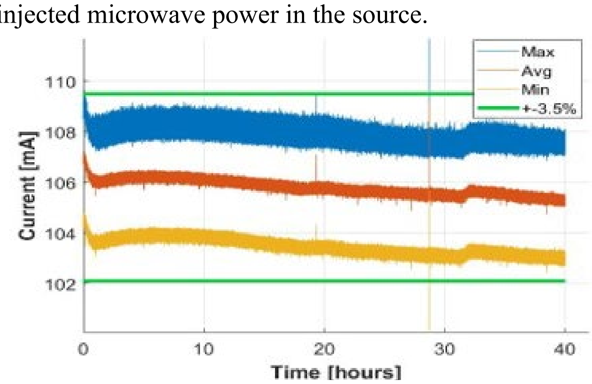

Figure 5: Pulse to pulse stability.

CONCLUSION

We have tested different methods to send to the ESS linac a modulable amount of beam current. The most appropriate methods are the use of the HSMDIS magnetic configuration, which enables high linearity between beam current intensity and injected microwave power to the plasma chamber, and the chopper beam pulse length modulation. The other tested methods do not guarantee a constant beam pulse modulation and a constant beam emittance shape.

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