A MICROWAVE ION SOURCE FOR PULSED PROTON BEAM PRODUCTION AT ESS-BILBAO

R. Miracoli*, I. Arredondo, D. Belver, I. Bustinduy, J. Corres, P. Echevarria, M. Eguiraun, Z. Izaola, N. Garmendia, P. Gonzalez, L. Muguira, I. Rueda, ESS-Bilbao, Spain

Abstract

Ion Source Hydrogen Positive (ISHP) is a microwave discharge installed at ESS Bilbao in Spain. This source will be employed in future application of high proton current in the field of research projects and for industrial processes. ISHP produces over 30 mA of pulsed proton beam by operating at 2.7 GHz. The magnetic field is produced by two independently movable coil pair and the extraction system is composed of a plasma electrode at high voltage platform potential, two ground electrodes and a negatively biased screening electrode inserted between the ground electrodes. The last three electrodes are contained in the extraction column, and can be moved as a group by stepper motors, to change the distance between the plasma electrode and first ground electrode. Measurements with different extraction system setups will be described to show the improvement of the beam intensity and beam emittance.

INTRODUCTION

The microwave discharge ion sources for proton production are widely employed in many areas of the research and for a growing number of industrial application, because they have many advantages in terms of compactness, high reliability, reproducibility, and low maintenance. These sources are used to work at low frequency and they require only an axial magnetic field distribution in order to dissociate the H_2 molecules and to produce high proton beams. At ESS Bilbao there is a very versatile proton source, ISHP that is able to support a wide variety of experiment. In fact the source can work for different values of duty cycle and for each configuration it's possible to optimize the magnetic confinement by changing the solenoid position and coils current. Moreover it's possible to change the distance between the plasma electrode and the puller electrode, adapting the beam dynamics with the extraction voltage and plasma conditions.

PROTON SOURCE

ISHP is composed by a water-cooled, cylindrical plasma chamber, made of copper 97 mm in length and 80 mm in diameter. A RF generator produces continuous or pulsed signal at the resonant frequency of 2.7 GHz, the microwaves, then, are amplified by a 2 kW, S-band satellite communications Klystron. The RF chain is, also, composed of a circulator with a water load to protect the klystron from excessive reflected power, a triple stub tuner placed between two directional couplers, is used to match plasma impedance with that of the waveguide. The tuner is composed of three rods that can penetrate inside the waveguide allowing to match the plasma load to impedance of the power transmitter system to transfer the maximum power [1, 2]. The microwave line also comprises a quartz RF window acting as a vacuum seal, a E-plane bend and a coupler, that is a double ridge stepped waveguide transition. The last one is a matching transformer which couples the rectangular waveguide to the plasma chamber and concentrates the electromagnetic field increasing plasma density [3].

The extraction system is composed of a plasma electrode at high voltage platform potential, two ground electrodes, and a negatively biased screening electrode (repeller) inserted between the ground electrodes. The last three electrodes are contained in the extraction column, and can be moved as a group by stepper motors, to change the distance between the plasma electrode and first ground electrode. In this way it can be possible to optimize the beam focusing for different experimental set-ups in terms of extraction voltage, plasma parameters, and beam current. The plasma electrode has 7.5 mm diameter aperture, and is made of copper plated pure iron. The ion source, the microwave line, and their complementary components are installed on a 75 kV high voltage platform.

Figure 1: Layout of ISHP source: the klystron, the RF chain and components, and the plasma chamber are installed on a high voltage platform.

Magnetic System

At 2.7 GHz the resonant field (B_{ECR}) is 0.964 T. The B_{ECR} is provided by two movable solenoids, shown in fig-

* rmiracoli@essbilbao.org

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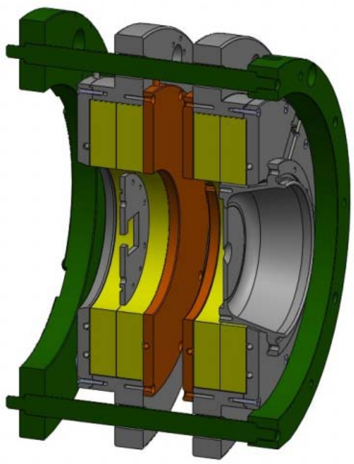

Figure 2: A scheme of the Magnetic System: in yellow the 4 coils, in grey the pure iron part, in green the stainless steel component and in orange the water cooling system.

ure 2, each solenoid can be moved independently by two stepping motors. Moreover each solenoid is divided in two coils, independently powered and enclosed by a ferromagnetic yoke. In figure 3 the blue line is the simulation of the axial magnetic field along chamber axis, obtained with the original magnetic system: B_z was too high in the extraction region where is necessary to limit the risks of breakdown. In order to limit the risks of Penning discharge in region of large electric field and cross magnetic induction it has been chosen to replace the orignal copper plasma electrode with a new one made in soft iron, in such a way the magnetic components can close the magnetic return path, and decreases the magnetic field in the extraction region. Moreover the firsts plasmas weren't stable and high values of reflected powers have been measured, since the microwaves could be absorbed inside the coupler at cyclotron harmonics. We have thought to put a soft iron plate between the coupler and plasma chamber, shown in figure 2. 3D finite-element simulation Comsol were, also, used to verify that the new magnetic system was able to produce a magnetic field higher than B_{ECR} inside the plasma chamber, in figure 3 there is a comparison between the two magnetic systems [4]. To test the accuracy of the simulations, the axial magnetic field B_z was measured with a Hall probe along the centerline of the chamber. The experimental results show a good agreement between the measured and simulated fields; there are deviations of only tenths of mT [4].

LEBT

The Low Energy Beam Transport (LEBT), following the extraction system, is nowadays composed of two vacuum vessel, as shown in figure 4. In each diagnostic chamber there is an ACCT to determine the beam losses in LEBT section, and a wire scanner in order to measure the beam profile produce by the source by changing the extraction gap

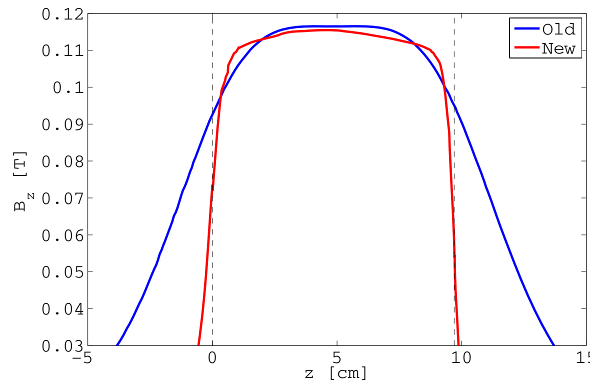

Figure 3: Comparison between the old and the new magnetic system.

and other plasma parameters. Between the vacuum vessel there is a solenoid, that have two steerers located inside it.

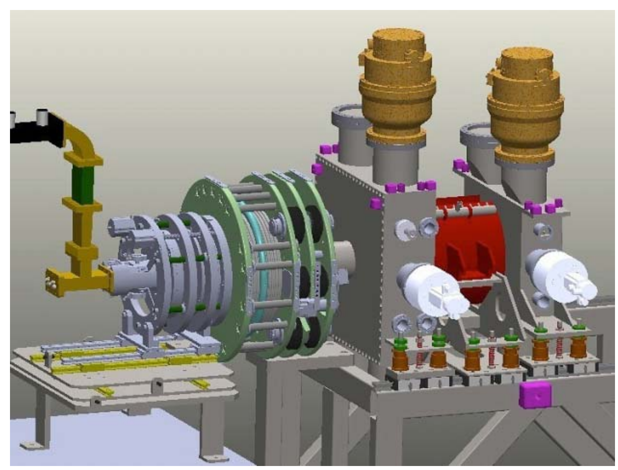

Figure 4: Layout of ISHP LEBT.

EXPERIMENTAL RESULTS

One of the peculiarities of our source is the possibility to move the electrodes of the extraction system. By changing the distance between the plasma electrode and the puller one changes the beam focusing, so it effects the beam density that reach the two ACCT, the beam shape and beam divergence. In order to find the optimal extraction gap the measurements were performed through several days with differently tunned plasmas. To get the profile of the beam, two wire scanners have been used. The wire scanners consist of two 0.2 mm tungsten wires mounted on the same support, we can chose the start and the stop of the measurements, the distance between the acquisition point and for each position we can chose the number of the pulse to be averaged. While the device sweeps the wires cross the beam, carried out a signal proportional with the number of the particles interacting with the wire, so the beam profile is acquired pulse by pulse.

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The distance between the plasma electrode and the puller (the extraction gap) has been moved from 8.5 mm to 14 mm. In these measurements we fixed the extraction voltage at 45 kV and the microwave power at 600 W; the beam pulse was 1.5 ms and the repetition rate was 10 Hz. For each position the source parameters have been set in order to extract stable and intense beams, after that two wire scanners have been used to acquire the beam profile. Typical profiles measurements are shown in figure 5, where the signals are carried out by means of the wire scanner located in the first vacuum vessel and by putting a beam collimator in front of the wire scanner (to avoid unwanted particles that cause to increase beam size). The advantage to have a vacuum vessel next to the extraction system is to have the opportunity to investigate how the plasma parameters can affect the beam without the use of magnetic lens.

Figure 5 shows beam profiles for three values of the extraction gap: 8.5 , 10 and 11 mm, and for each curve the signals intensity, the peak position and sigma have been calculated, see table 1. The wire scanner signals are higher in correspondence of smaller extraction gap (8.5 mm), and if we compare the distance between the two peaks of the beam profiles, it is evident that at 8.5 mm increase the beam dimension, in correspondence of higher currents. Moreover the transmission of the beam trough the LEBT has been measured, by comparing the current of the two ACCT and by using the solenoid. The beam transmission is about 74 % at 8.5 mm, then it starts to increase and reaches 78 % only for extraction gaps included between 9.5 and 10.5 mm, at higher distances the transmission decrease until 76 %. Additional measurements will be done in order to verify the optimal extraction gap at different values of the platform voltage. At the same time the measures of beam emittance will be carried out in the next month by means of a pepper pot, that will be located in the second vacuum vessel and will yield more information about beam divergence

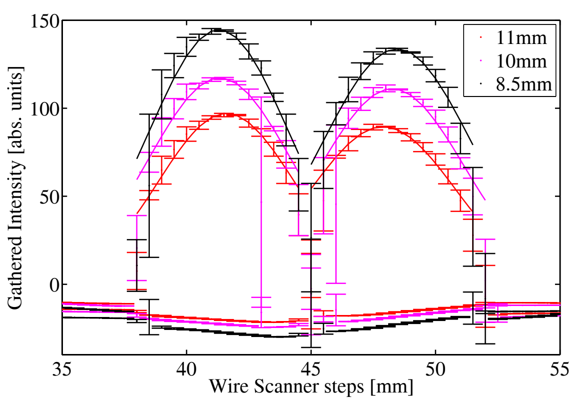

Figure 5: Typical profile measurements, obtained for three different extraction gap: 8.5 mm (black), 10 mm (pink) and 11 mm (red).

Other measurements has been done by changing the duty cycle (pulse width and repetition rate). The typical wave form of the pulse detected in two ACCT is shown in figure 6, the operating parameters were: RF power 600 W, platform voltage 45 kV, and repeller −1.25 kV, pulse width 3 ms and repetition rate 20 Hz. The rise time is about 100 µs.

Table 1: Characterization of beam profile.

	Intensity [a. u.]	Peak position[mm]	σ [mm]
8.5 mm			
$Wire_1$	144.68	41.3	2.77
$Wire_2$	133.83	48.46	2.97
10 mm			
$Wire_1$	117.26	41.33	2.86
$Wire_2$	111.16	48.26	2.88
11 mm			
$Wire_1$	97.14	41.6	2.7
$Wire_2$	89.57	47.89	2.89

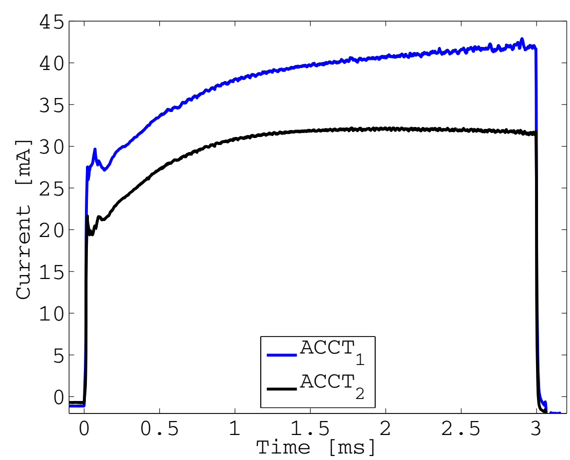

Figure 6: 45 KeV extracted beam current measured with two ACCT located in the first and the second vacuum vessel respectively.

CONCLUSION

IHSP is a versatile proton source that is able to produce pulsed current higher than 45 mA and to work in pulsed mode for different pulse length (from 0.6 ms to a few ms) and repetition rate (from 1 to 40 Hz), by adapting in each configuration the magnetic confinement. Moreover by working at several values of platform voltage it can always optimize the beam focusing, adapting the extraction gap.

Furthermore in the future it will be necessary optimize the production of H^+, and in this respect the magnetic profile plays an important role not only in the heating processes but also affects the ion lifetime, so the current coils should be set to maximize the proton fraction. And the same time by working in pulsed mode it has been noticed in previous works [5] that the production of protons is affected by the pulse width and microwave power.

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