CHARACTERIZATION OF THE AMIT INTERNAL ION SOURCE WITH A DEVOTED DC EXTRACTION TEST BENCH*

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Abstract

With the main aim of a compact machine for 18F and 11C radioisotope production, AMIT cyclotron relies on a superconducting 4T magnet with an internal cold cathode PIG ion source for H- production. Given the limited access to the ion source in the cyclotron as well the reduced number of beam diagnostics, an experimental facility was proposed for the commissioning of such ion source. The versatility of this test bench, which includes a movable puller, gives us the opportunity to validate and characterize the ion source behavior as well as to optimize the H- production. In a first stage, the discharge characteristics of the ion source has been studied in the CIEMAT IST facilities.

INTRODUCTION

The required high magnetic field (4 T) for the compact design of the AMIT superconducting cyclotron (8.5 MeV) makes the classical cyclotron choice to be considerably less complicated than the corresponding isochronous solution which requires more accurate magnetic field and also includes the flutter issue [1]. A combination of high magnetic field and high alternating electric fields accelerates the negative charged particles from the central axis, where they are injected, in an outward spiraling path. The magnetic field decreases along the radius of the orbit providing radial and axial stability of the beam (weak focusing). The oscillation frequency of the gap voltage remains constant while the ion orbital frequency decreases due to the relativistic mass increase with the energy and to the radial decrease of the magnetic field. In the extraction radius the negative ions pass through a thin carbon foil that strip the electrons producing a proton beam. The simplicity and compactness of cold-cathode PIG internal ion source makes the most frequent solutions for cyclotrons used for PET facilities. For these reasons, a prototype of a cold cathode PIG ion source of the cyclotron has been developed in CIEMAT in order to study its discharge characteristics and improve its efficiency. The structure of the ion source and its working parameters plays an essential role in the determination of the final design of the whole cyclotron. Therefore, after some parameters of operation are fixed, the source geometry can be tuned to improve the production of negative ions at reduced gas flow rates.

ION SOURCE

The ion source is a compact cold-cathode PIG with a simple internal structure. It consists of two main components, the ion source chimney or anode made of a copper-tungsten alloy and two cathodes made of tantalum. The cathodes are connected to the negative output of the ion source power supply and the anode is at ground potential. Hydrogen is injected directly into the source through the cathodes cavity. The pressure inside the hollow anode is controlled by the gas flow rate. To start the hydrogen breakdown, the arc voltage could be increased up to -3 kV and the gas flow up to 10 sccm. The arc strikes in a few seconds. Thereafter, the voltage needed to sustain the arc depends on the arc current and gas pressure; for normal operation it is bellow than 1 kV. The gas pressure can be reduced to the operating level and the arc current can be adjusted to the setpoint. Water cooling lines, gas lines and electrical lead are housed in cathode supports.

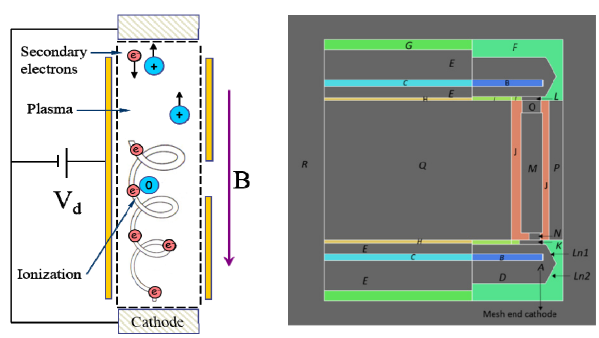

Figure 1: Scheme of ion source design.

The anode has a slit opening along the side of the ion source where the H- ions are extracted. In the volume of the hollow anode cylinder, the negative ions are formed by dissociative attachment between excited gas molecules and very cold electrons. The low binding energy of H- (around 0.75 eV) allows that the extra electron is easily

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detached. There are several channels for this, but one of them has a very large cross section for energies higher than 3 eV. To compensate the destruction channel, the plasma source designs have a region where there are cold electrons about 1 eV to produce negative ions and fast electrons are excluded (see Fig. 1). Negative ions are formed mostly outside the arc column by plasma electrons that have diffused out of the column. Therefore, negative ions will basically only exist in the outer shell of the plasma and an expansion gap is added between the arc column and extraction slit [2].

In order to define the edge of the plasma with respect of the slit, a restriction in the axis of the anode has been included. Therefore the plasma column could be positioned close to the slit opening to improve the production probability and increase the efficiency of the ion extraction. An additional restrictor ring can be used can be used to reduce the diameter of the hollow anode.

TEST FACILITY

The ion source should be optimized to maximize the current extraction. Therefore, a dedicated test facility has been designed, constructed and commissioned in CIEMAT for the optimization of this kind of ion sources. This test bench was carefully designed to minimize drawbacks as the high voltage loading spark, low vacuum level and non-stability of glow discharge in the extraction beam area. The ion source is installed in an extremely versatile vacuum chamber over a robust and low weight structure. The vacuum chamber containing the ion source and associated equipment is inserted inside a dipole electromagnet which has been built by ANTEC Magnets. The magnet, with circular pole, provides a uniform magnetic field inside the gap of 130mm. At maximum current of 300_A the magnetic field can be 0.86_T. (see Fig. 2)

Figure 2: Vacuum chamber insert in the dipole magnet.

To have a low stripping loss as well as a rapid pumping speed, the vacuum system uses two diffusion pumps of 1300 l/s for H_2 and one rotary vane vacuum pump of ~40 m^3/h. The gas handling system controls the flow rate of H_2 into the source in a range of 0 to 10 SCCM.

In this test, the ion source is grounded whereas the puller, at positive DC voltage, extracts the particles. An electrical shielding box is installed inside the vacuum chamber [3]. This box shields the applied electric field and therefore the trajectories of negative ions are only affected by the magnetic field which separates them for different q/m ratios. A beam probe, located according to H^- path, measures the H- current [4]. Electrons hardly enter in the measurement area with such strong magnetic field (orbit radius is much smaller). The collector plate also emit electrons when the ions impact on it. However, given the strong magnetic field and the fact there is no electric field to remove the electrons, they will probably not be able to escape the collector, so the beam intensity measurement will be fine (see Fig. 3).

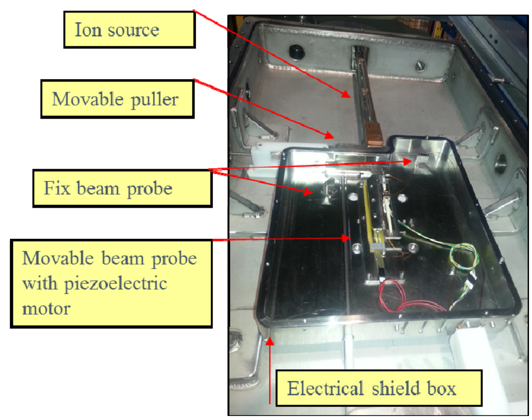

Figure 3: Vacuum chamber interior.

The HV test area is separated from the other working areas by a mesh fence of 2m high and has a system of protection against electrical hazards (see Fig. 4).

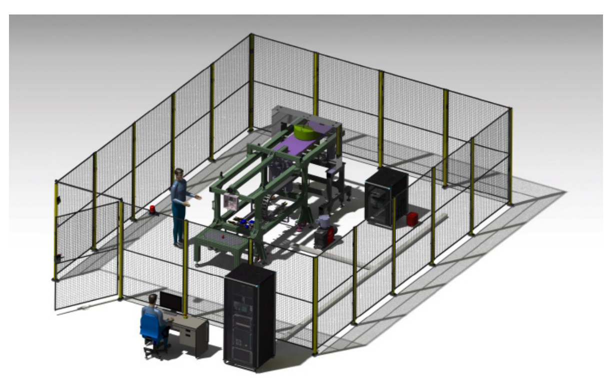

Figure 4: Test Facility.

RESULTS AND DISCUSSION

The PIG source has been setup inside the vacuum and the discharge characteristics of the ion source has been

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studied. The flow rate, vacuum system pressure, magnetic field, arc voltage and arc current have been recorded.

The electron emission is dominantly thermionic emission due heating of the cathode by back bombardment by the ions in the discharge. In this self-heated mode the voltage-current characteristic has a negative impedance and the ion source is affected mainly by gas flow and arc current. There is a little influence of the magnetic field on the discharge parameters as long as it reaches a certain value. For arc currents below 250 mA the electrons are mainly furnished by secondary emission and the impedance is high. When the current increases, the cathodes heat up and begin to supply electrons by thermionic emission

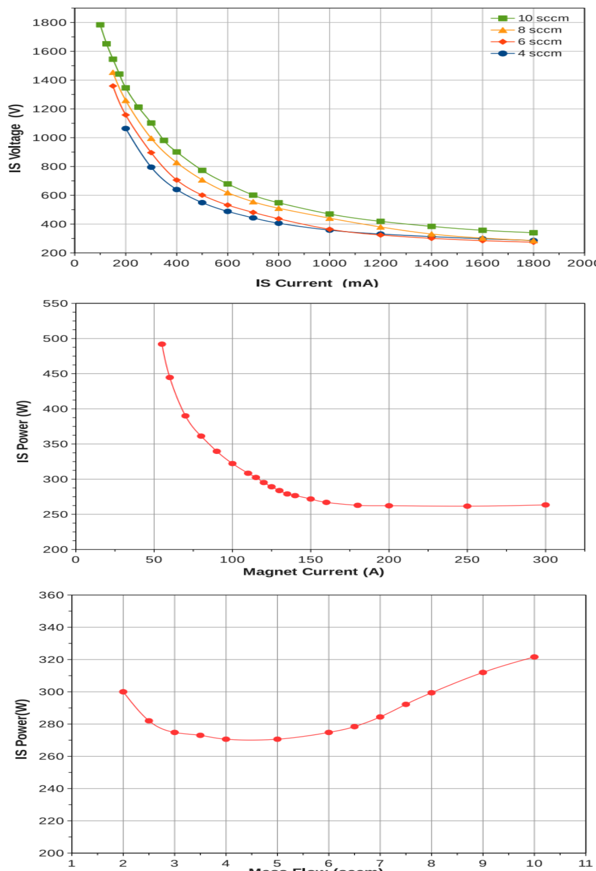

Figure 5: a) Arc voltage respect arc current with magnet coil current of 300A. b) Arc power respect magnet current., 6 sccm, 600 mA of Arc current c) Arc power for different mass flow rates with 600 mA of Arc current, 135 A of magnet coil current.

The experimental voltage-current curve agrees with the arc discharge characteristics of a PIG ion source where the impedance is positive for the cold cathode and negative for hot cathode source. The arc voltage decreases rapidly as the arc current increases and gradually saturates at high currents.

There is a little influence of the magnetic field on the discharge parameters as long as it reaches certain value.

The arc power goes through a minimum, (aprox. 4 sccm, then increases as the gas flow increases. As the gas flow rate increases initially, larger pressure means an increase in neutral density, so more atoms or molecules are available for plasma production and plasma resistance decreases. Then, the electron collision frequency increases and plasma resistance increases.

In a first stage the current of H^- ions has been measured in the beam probe getting a maximum current of ~170µA.

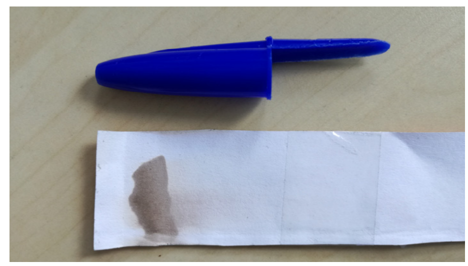

Figure 6: H^- profile after puller using a burnt paper.

CONCLUSION

The discharge characteristics of the baseline configuration of the cold cathode PIG ion source has been studied at different arc currents, gas flow rates and magnet fields. The performance of the ion source has had an expected behavior. H^- ions has been extracted and measured. Nevertheless the beam parameters have a strong dependence on the geometrical parameters such as the distance between the slit opening and the edge of the plasma column and shape of the plasma column. The influence of these parameters in the production of H^- ions will be studied in future experiments.

REFERENCES

[1] C.Oliver *et al.*, “Optimizing the radioisotope production with a weak focusing compact cyclotron”, in *Proc. 20th Int. Conf. on cyclotrons and their applications (CYCLOTRONS’13)*, Vancouver, Canada, Sep. 2013, paper WE4PB03, pp. 429-431.

[2] Kenneth W. Ehlers, “Design Considerations for High-Intensity Negative Ion Sources”. *Nuc. Instr. & Method 32 (1965).*

[3] T. Wang, “Electrical shielding box measurement of the negative hydrogen beam from Penning Ion Gauge ion source”, *Review of Scientific Instruments 83 (2012).*

[4] R. Varela *et al.*, “Beam diagnostics design for a compact superconducting cyclotron for radioisotope production”, in Proc. *IBIC’16*, Barcelona, Spain, 2017, paper MOPG29.