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Development of high intensity ion sources for a Tandem-Electrostatic-Quadrupole facility for Accelerator-Based Boron Neutron Capture Therapy

J. Bergueiro [a,c], M. Igarzabal [a], J.C. Suarez Sandin [a], H.R. Somacal [a,b], V. Thatar Vento [a,c], H. Huck [a,b], A.A. Valda [a,b], M. Repetto [a], A.J. Kreiner [a,b,c,]*

[a] *Gerencia de Investigación y Aplicaciones, Comisión Nacional de Energía Atómica, Argentina*
[b] *Escuela de Ciencia y Tecnología, Universidad Nacional de San Martín, Argentina*
[c] *CONICET, Buenos Aires, Argentina*

A R T I C L E I N F O

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A B S T R A C T

Several ion sources have been developed and an ion source test stand has been mounted for the first stage of a Tandem-Electrostatic-Quadrupole facility For Accelerator-Based Boron Neutron Capture Therapy. A first source, designed, fabricated and tested is a dual chamber, filament driven and magnetically compressed volume plasma proton ion source. A 4 mA beam has been accelerated and transported into the suppressed Faraday cup. Extensive simulations of the sources have been performed using both 2D and 3D self-consistent codes.

1. Introduction

Within the frame of an ongoing project to develop a folded Tandem-Electrostatic-Quadrupole (TESQ) accelerator facility for Accelerator-Based Boron Neutron Capture Therapy (AB-BNCT) based on the $^{7}\mathrm{Li}(p,n)^{7}\mathrm{Be}$ reaction at 2.4 MeV, or the $^{9}\mathrm{Be}(d,n)^{10}\mathrm{B}$ reaction at 1.2 MeV in the first stage, we discuss here the present status of the development of high-intensity proton ion sources to produce multi-mA beams.

2. Test stand

One of the subsystems necessary for a TESQ facility is the ion source. In order to produce sufficiently high neutron fluxes we aim at accelerating intense proton or deuteron beams of up to 30 mA. A complete test stand has been set-up and several ion sources are being developed. The work has concentrated on volume plasma, filament driven and magnetic field compressed plasma ion sources. Dual chamber (plasma generating chamber and expansion cup) monocusp, duoplasmatrons and multicusp sources are being designed, built and already tested in the first case (Huck et al., 2005, Brown, 2004).

The test stand consists of an insulated platform (Fig. 1) capable of holding voltages up to 100 kV. The ion source is mounted at high voltage and the necessary power for heating the tungsten filament (several tens of amperes and volts) and for sustaining the arc discharge against the anode is furnished through an insulation transformer capable of holding up to 100 kV and transferring up to 10 kW from ground. Furthermore, the test stand beam line has extraction electrodes following the ion source, a ceramic-metal acceleration tube, which houses these electrodes, a diagnostic chamber with a viewing port and a ladder with a target and collimator holding capability and finally a refrigerated and suppressed Faraday cup to integrate the accelerated ion beam. Several 50 kV and 60 mA high voltage supplies are used for powering the different electrodes.

3. Ion source development

A dual chamber, filament driven and magnetically compressed monocusp, volume plasma proton ion source has been designed, fabricated and tested. It consists of a plasma generating chamber with a tungsten filament discharging against an anode within a plasma of relatively high density, surrounded by permanent magnets with their north poles facing the axis of the cylindrical chamber in order to generate a monocusp magnetic field. This longitudinal field, parallel to the axis, compresses and concentrates the electron discharge against the aperture connecting to a subsequent expansion cup. The magnetic field penetrates into that chamber further contributing to enhancing the hydrogen gas ionization efficiency of the electron discharge (Figs. 2–4).

Different high current ion sources are being developed. In particular Figs. 5 and 6 show a dual chamber plasma volume

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* Corresponding author at: Gerencia de Investigación y Aplicaciones, Comisión Nacional de Energía Atómica, Argentina.
E-mail address: kreiner@tandar.cnea.gov.ar (A.J. Kreiner).

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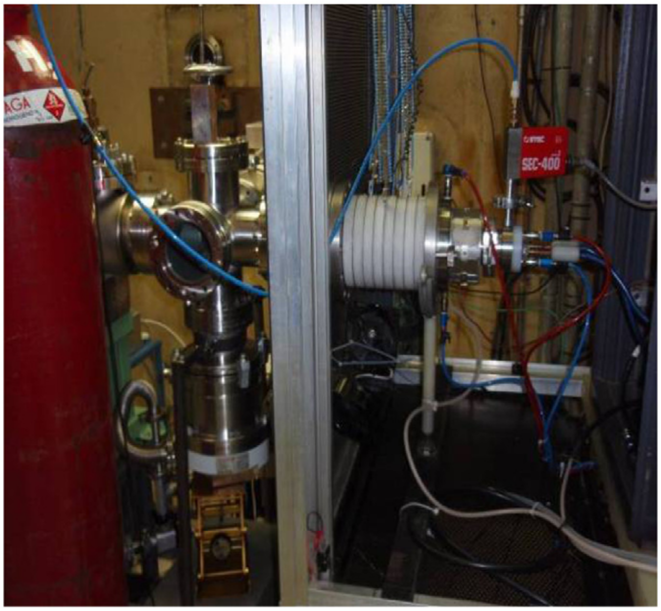

Fig. 1. Ion source test stand, displaying an ion source, an acceleration tube and the diagnostic chamber with target ladder and pumping station (from right to left).

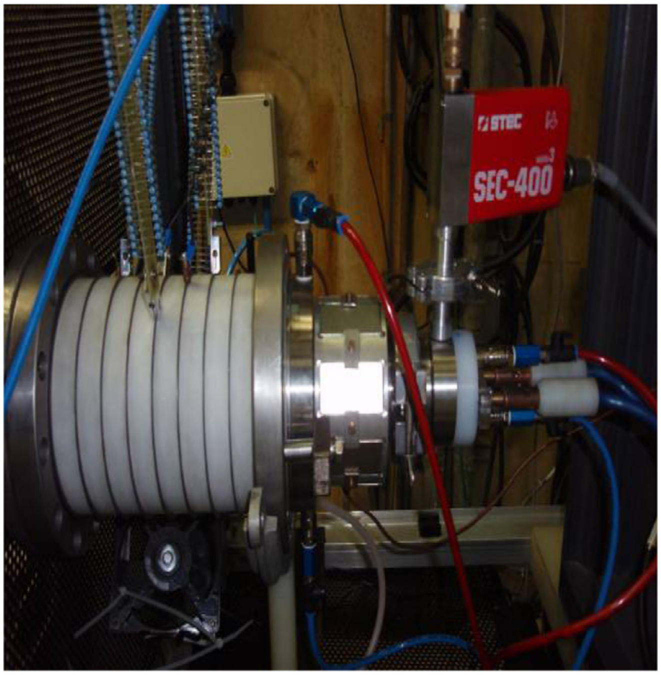

Fig. 2. Closer view of the test stand, displaying the dual chamber ion source with power feedthroughs (right hand side) gas inlet and gauge, girdle of cusp magnets, and acceleration tube.

source already constructed and assembled. This source, working with hydrogen, in combination with a pre-acceleration system of electrodes has produced an intense proton beam of about 50 mA.

4. Beam transport

The system is completed by an extraction system (see Figs. 7–9). Without transport through the beam line into the Faraday cup, the ion source has been shown to deliver high proton currents up to 50 mA with extraction voltages of up to 40–50 kV. In addition a beam of about 4 mA, with a cross section of about 1 cm diameter, has been accelerated and transported into the suppressed Faraday cup, 1 m downstream. A diagnostic system based on the fluorescence induced in the residual gas is being developed. Extensive simulations of the source and extraction have been performed using both 2D and 3D self-consistent codes (see Fig. 9).

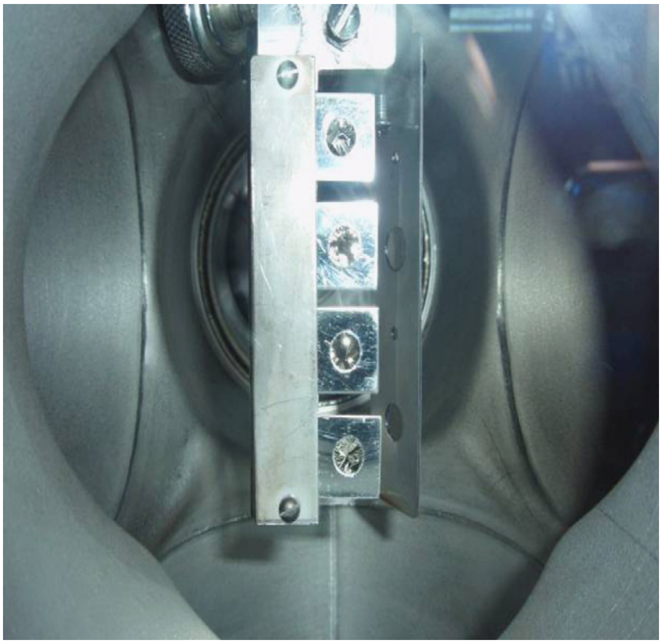

Fig. 3. Stripper, phosphor screen and collimator ladder seen through the viewing port in the diagnostic chamber.

Fig. 4. Front view of the test stand, displaying the two 50 kV, 60 mA high voltage supplies (bottom panels) used for polarizing the ion source and an extraction electrode. Within the upper grounded Faraday cage one sees other power supplies for filament and gas discharge mounted on an insulated platform.

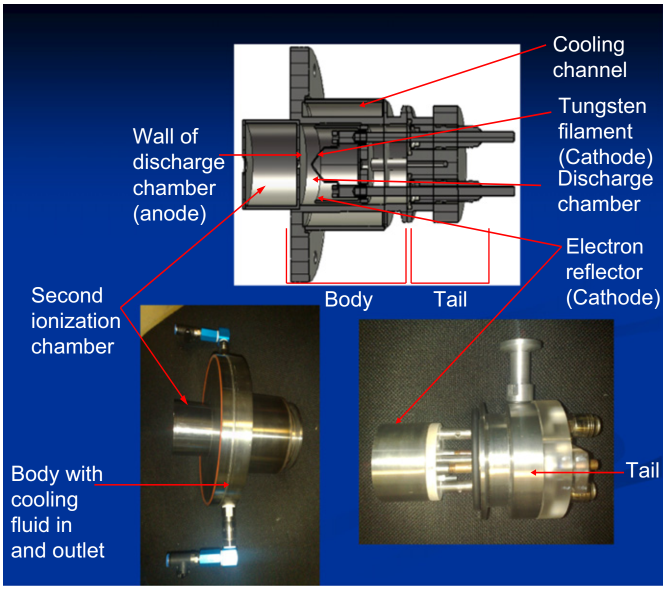

Fig. 5. Dual chamber filament driven plasma volume source.

Fig. 6. Output plasma electrode.

Fig. 7. First extraction electrode within acceleration tube (pointing towards the ion source).

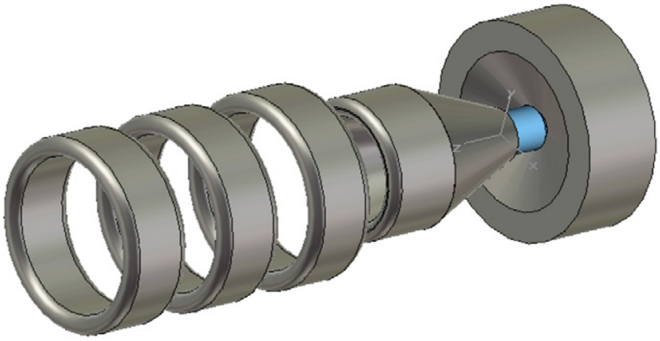

Fig. 8. Extraction and focusing electrodes within acceleration tube (schematic).

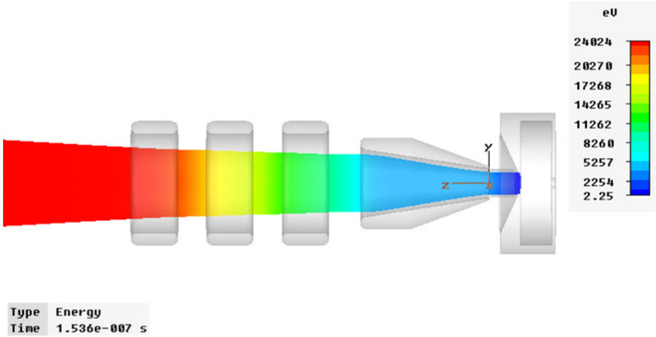

Fig. 9. Self-consistent simulation through the extraction and focusing electrodes within the acceleration tube.

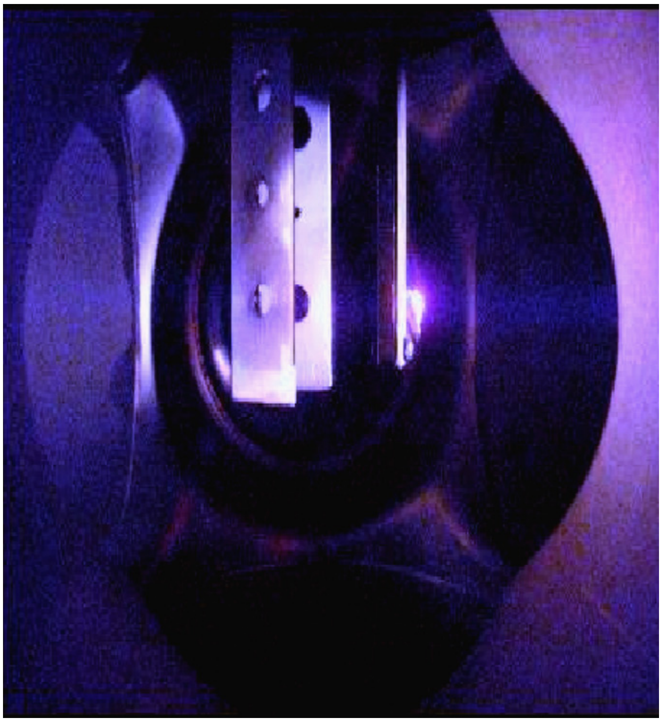

Fig. 10. Photograph of induced fluorescence of proton beam in the residual H_2 gas of the test stand beam line. The proton beam is impinging from the right-hand side on a phosphor screen.

Fig. 10 shows a photograph of a proton beam revealed through the induced fluorescence in the residual H_2 gas of the beam line impinging on a phosphorescent screen. This beam has been used for testing the durability of different stripper foils of potential interest for the tandem terminal.

5. Summary and conclusions

An ion source test stand has been mounted, which consists of an insulated platform capable of holding voltages up to 100 kV to operate the ion sources. The test stand beam line has extraction electrodes following the ion source, a ceramic-metal acceleration tube, a diagnostic chamber with a viewing port and a ladder with target and collimator holding capability and finally a refrigerated and suppressed Faraday cup to integrate the accelerated ion beam. A dual chamber, filament driven and magnetically compressed monocusp, volume plasma proton ion source has been designed, fabricated and tested. It consists of a plasma generating chamber with a tungsten filament discharging against an anode within a plasma of relatively high density. The system is completed by an extraction system. Without transport through the line into the Faraday cup, the ion source has been shown to deliver high proton currents up to 50 mA with extraction voltages up to 40–50 kV, while a beam of about 4 mA has been accelerated and transported into the suppressed Faraday cup. Also a duoplasmatron source has been built which will be tested in the near future. Extensive simulations of the sources and the extraction have been performed using both 2D and 3D self-consistent codes. In the near future the source will be coupled to the accelerator prototype and more extensive testing on the transport and acceleration of the beam will start. The next goal is to transport a 10 mA beam up to a target placed at 600 kV, within the high voltage dome of the prototype.

References

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