TESTS OF THE VERSATILE ION SOURCE (VIS) FOR HIGH POWER PROTON BEAM PRODUCTION*

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Abstract

The sources adapted to beam production for high power proton accelerators must obey to the request of high brightness, stability and reliability. The Versatile Ion Source (VIS) is based on permanent magnets to produce an off-resonance microwave discharge (the maximum field value on the chamber axis is around 0.1 T). It operates up to 75 kV without a bulky high voltage platform, producing several tens of mA of proton beams and monocharged ions. The microwave injection system and the extraction electrodes geometry have been designed in order to optimize the beam brightness. Moreover, the VIS source ensures long time operations without maintenance and high reliability. A description of the main components and of the source performances is given in the following. A brief summary of the possible next developments is also presented, particularly for pulsed mode operations, that are relevant for some future projects (e.g. the European Spallation Source of Lund).

INTRODUCTION

The characteristics of the ideal injector for high power proton accelerators (HPPA) have been deeply studied at INFN-LNS with the TRIPS ion source [1], now in operation at INFN-LNL, Legnaro.

Its aim was to produce with high reliability a minimum proton current of 35 mA with a rms normalyzed emittance lower than 0.2 π mm mrad for an operating voltage of 80 kV. All the required performances have been reached with a good reliability [2]. A more compact version, called VIS (Versatile Ion Source), has been designed and built at INFN-LNS, with similar goals but using permanent magnets and a simplified extraction geometry and extraction column, in order to permit long term operations with high reliability.

The layout of the VIS source is reported in figure 1. The source body consists of a water-cooled copper plasma chamber (100 mm long and 90 mm diameter) surrounded by permanent magnets generating a 0.1 T almost flat magnetic field along the axis (fig. 2). Due to the outer iron components it quickly falls off in the extraction region. The stray fields in the extraction area are significantly lower than for TRIPS. Considering that the conductance is about the same, the conditions for a Penning discharge are not occurring.

A 2 kW 2.45 GHz magnetron provides the microwaves to the plasma chamber through a WR284 rectangular waveguide. The ionic component of the plasma is then extracted by means of a four electrodes extraction system. The low energy beam transport line (LEBT) shown in figure 3 allows the beam analysis and it consists of a focusing solenoid, a four-sector diaphragm to measure beam misalignements and dishomogeneities, a direct current transformer (DCCT), a 30° bending magnet and an insulated beam stop to measure the beam current on each arm. Two turbomolecular pumps are used to get in the plasma chamber and in the LEBT a pressure lower than $1 \cdot 10^{-6}$ mbar.

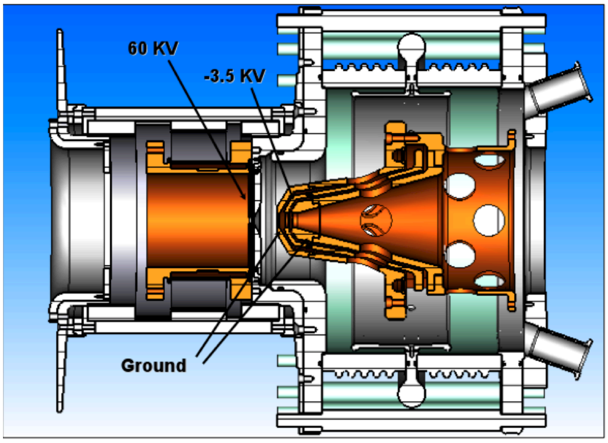

Figure 1: A cross section of the VIS source.

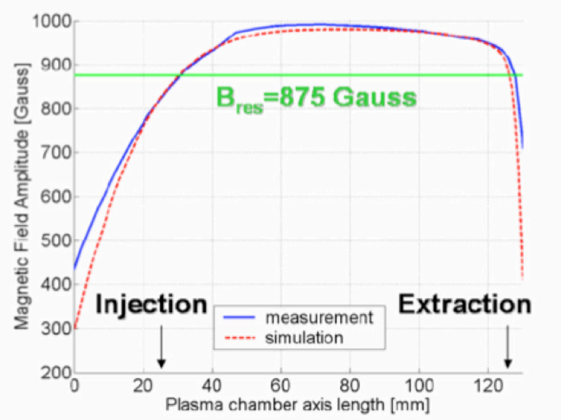

Figure 2: Magnetic field profile.

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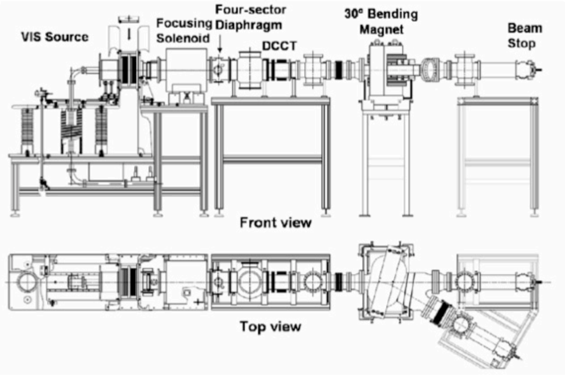

Figure 3: The VIS Source with the LEBT.

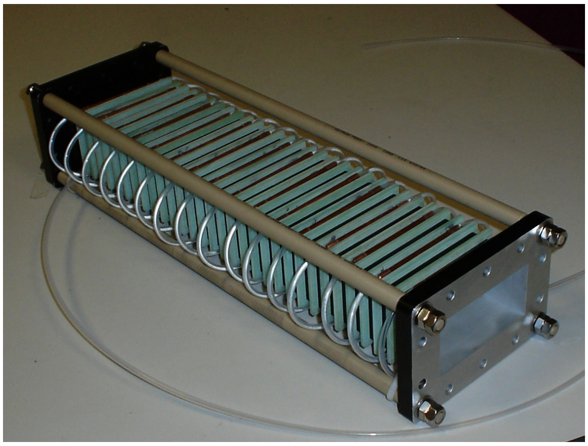

Figure 4: The innovative 80 kV dc break.

All the devices needed for the computer control are located at ground potential. This is the main advantage with respect to the TRIPS source along with the use of permanent magnets and the insulation of the microwave line and of the gas pipe. This choice permits to avoid any electronic device at high voltage minimizing the size of the high voltage platform and making not necessary the insulation transformer, leaving only the source, together with the microwave line up to the dc-break, at high potential.

The microwave line is the result of an optimization study carried out with tools for high frequency structures simulators: this permitted to reduce the microwave losses, simultaneously with an adequate match with the plasma chamber. A 2.45 GHz 2 kW magnetron excites the TE_{10} dominant mode in the WR340 (86.4 mm x 43.2 mm) waveguide. An adequate matching impedance with the plasma chamber is obtained by means of an automatic tuning unit that minimizes the reflected power. The dual arm directional coupler will be used to measure the forward and the reflected power.

The waveguide DC-break has been designed and realized at INFN-LNS (fig. 4). It is made of aluminum sections of a WR340 waveguide insulated one each other by means of fiberglass disks. The conductive parts will be fixed to voltages gradually decreasing, from 80 kV to ground, keeping low the insertion loss, below 1.4 dB [3].

The five electrodes topology, employed on TRIPS for the on-line optimization of the extracted beam over a wide current range (20-60 mA), has been simplified to permit very reliable operations for a beam current around 40 mA at an extraction voltage of 60 kV. The final optics of the extraction system is based on four electrodes: the plasma electrode with an aperture of 6 mm, followed by two grounded electrodes with the repeller one in between. The simulations suggested that a compact extraction column and a simplified power supplies' setup may increase the reliability without losing in terms of beam emittance. The results confirmed the validity of our approach; in fact the current is typically around the chosen value of 40 mA (fig. 5), for different operational conditions (the main tuning parameter being the power and the pressure).

The proton fraction against the microwave power was instead observed to increase continuously with the microwave power from 76 to 89 % for values ranging from 0.4 to 1 kW [4]. Figure 6 shows the beam current for different magnetic settings and microwave power ranging from 600 to 1200 W. Similar results have been observed for lower pressures.

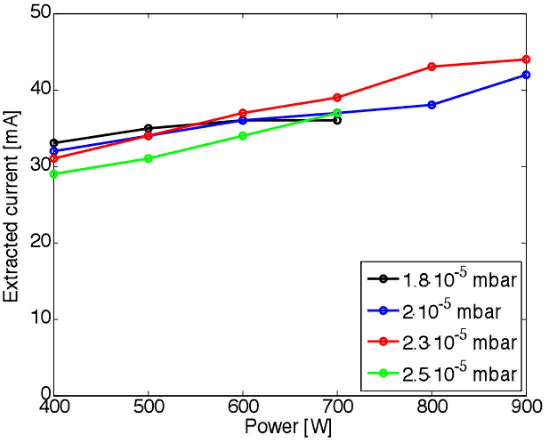

Figure 5: Beam current vs. the the power at different pressure.

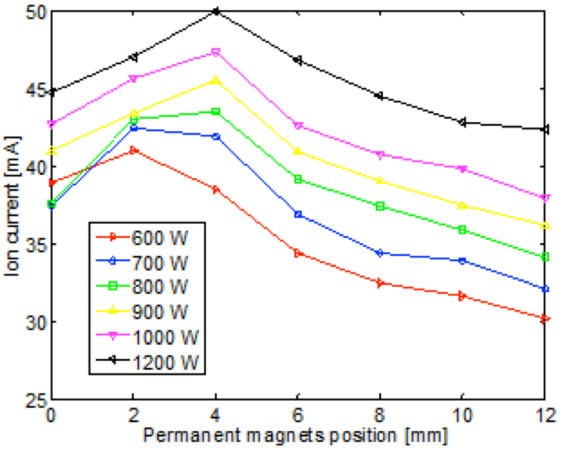

Figure 6: Beam current vs. permanent magnets position.

EMITTANCE MEASUREMENTS

The emittance has been measured by means of an emittance measurement unit (EMU), provided by the CEA/Saclay SILHI group and described in detail in ref. [5]. The emittance measurements have been carried out for different positions of the permanent magnets in order to check the role of the fine magnetic field tuning on the beam. For each position we investigated the emittance variation by changing the puller voltage, the microwave power and the gas pressure.

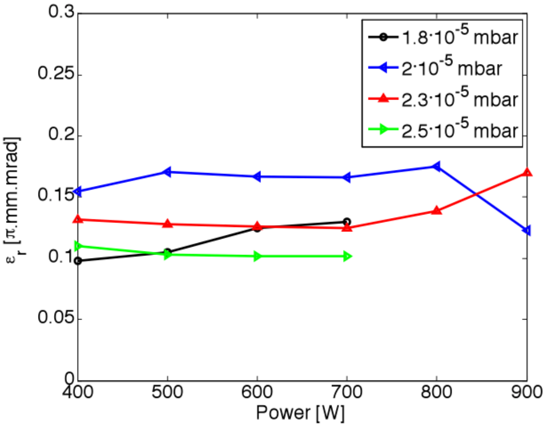

Figure 7: Beam emittance vs. microwave power.

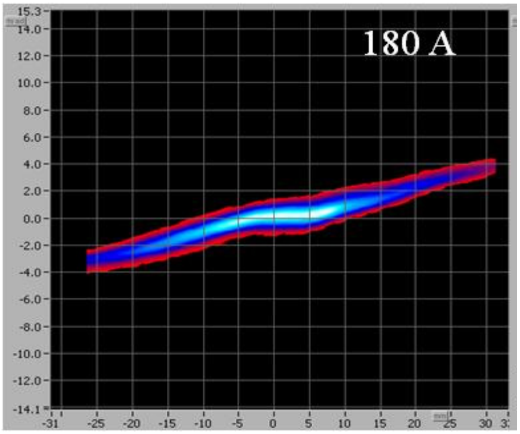

Figure 8: Proton beam emittance plot (P_{source}=2.3•10^{-5} mbar, I=42 mA, ε_N=0.17 π mm mrad, P_{rf}= 900 W).

A detailed report of the emittance measurement can be found in ref [4]. From these measurements it can be inferred that by optimizing the position of the permanent magnets, and therefore the position of the ECR surface, the rms normalized emittance for a proton beam of 42 mA ranges between 0.1 and 0.15 π mm mrad (fig. 7), without the space charge compensation due to the gas injection in the beamline. It must be pointed out that the emittance obtained with the TRIPS source (with the same emittance measurement device) [2] is about the same. Figure 8 shows one of the worst emittance plot (ε_N=0.17 π mm mrad at 900 W) which presents the typical shape due to the solenoidal field aberrations. These asymmetries in the emittance have been observed mostly for large power.

PERSPECTIVES

The VIS source will be used in the next two years as a testbench for new techniques to improve the beam brightness, ranging from the use of different methods to couple the microwave power to the plasma, to the use of electron donors and of different methods to neutralize the space charge. A different scheme of plasma excitation will be also tried, along with the operations in pulsed mode, with the 4% duty cycle needed for the project of the Linac for the European Spallation Source (ESS) at Lund, Sweden.

The tests are expected to begin in 2011, once that the VIS source will be moved to a new testbench at INFN-LNS, which will be used thereinafter to install the proton source to be built for the ESS project, according to the requirements presented in tab. 1.

Table 1: Main Requirements of the Beam for ESS

Input	**Nominal**	**Upgrade**
Average beam power	5.0 MW	7.5 MW
Macro-pulse length	2.0 ms	2.0 ms
Pulse repetition rate	20 Hz	20 Hz
Proton kinetic energy	2.5 GeV	2.5 GeV
Peak coupler power	1.0 MW	1.0 MW
Beam loss rate	<1.0 W/m	<1.0 W/m
Output	**Nominal**	**Upgrade**
Duty factor	0.04	0.04
Average pulse current	50 mA	75 mA
Ion source current	60 mA	90 mA
Total linac length	418 m	418 m

ACKNOWLEDGEMENTS

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