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 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 [1]. The plasma chamber is coupled with a 2.45 GHz magnetron through a microwave line that has been deeply studied with tools for high frequency structures simulations in order to optimize the impedance match, to maximize the electric field in the plasma chamber and to reduce the microwave losses in the 80 kV DC-break. [2,3].The magnetic system is composed by three NdFeB rings permanent magnets; the stainless steel separation rings and inner and outer iron components has been adapted to the production of an almost flat magnetic field profile along the whole plasma chamber. Moreover, the magnetic field quickly falls in the extraction region along the axis and off axis as for other sources [4], thus minimizing the stray field effect on the extracted beam as well as the Penning discharges in the first gap. The ionic component of the plasma produced in the chamber is then extracted by means of a four electrodes extraction system. It consists of a plasma electrode made of molybdenum at 65 kV voltage, two water cooled grounded electrodes and a 3.5 kV negatively biased screening electrode inserted between them to stop the secondary electrons due to residual gas ionization, backstreaming to the extraction area. The VIS extraction has been optimized to work around 40 mA and a theoretical value of 0.07 π mm mrad normalized emittance has been calculated, i.e. fulfilling the requirement of high brightness. The low energy beam transport line (LEBT) allows the beam analysis and it consists of a focusing solenoid, a four-sector diaphragm to measure the beam misalignments, a Direct-Current Current Transformer (DCCT), a 30° bending magnet and an insulated beam stop to measure the beam current. author should submit the PostScript and all of the source files (text and figures), to enable the paper to be reconstructed if there are processing difficulties.

The emittance has been measured by means of an emittance measurement unit (EMU) provided by the CEA/Saclay SILHI group described in detail in ref[5]. The EMU was not originally considered in the design of the LEBT of VIS, but with minor beam line changes it has been easily installed.

Figure 1: The VIS Source with the Emittance Measurement unit.

EMITTANCE MEASUREMENTS

The emittance measurements have been carried out for different positions of the permanent magnets to check the role of the fine magnetic field tuning on the beam. For each position (see fig.2) we investigated the emittance variation by changing the puller voltage, the microwave power and the gas pressure.

For the different operational parameters, the beam current ranges from 30 to 50 mA for an extraction voltage of 60 kV and an extraction aperture of 8 mm.

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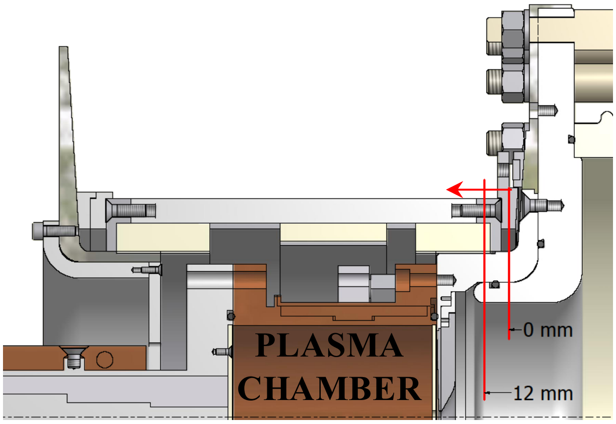

Figure 2: A cross section of the VIS body source: the permanent magnets assembly has been moved towards the injection side.

The figure 3 shows the comparison of the beam current for different magnetic settings and microwave power ranging from 600 to 1200 W.

Similar results have been observed for lower pressures but the peaks observed in the configurations 2÷4 mm are less pronounced.

An example of emittance measurements when the permanent magnets have been shifted toward the injection side of 8 mm is shown in figure 4.

Figure 5 shows the proton fraction against the microwave power measured when the permanent magnet are in the 4 mm configuration. It can be observed a value increasing continuously with the microwave power from 76 to 89 %. Moreover, by changing the permanent magnet position in step of two millimeters (i.e by slightly varying the magnetic induction on the extraction and injection sides) the proton fraction measured was always higher than 80 % for a RF power ranging from 0.4 to 1 kW.

In figure 6 the measurements carried out for different values of gas pressure are plotted with the permanent magnets in the 4 mm configuration. It can be observed that the beam divergence has the lowest values when the pressure (measured with a gauge mounted on the ground flange of the extraction column) is about $2.5 \cdot 10^{-5}$ mbar. Different values of extraction voltage have been used ranging from 55 to 65 kV: even at 55 kV the beam emittance was approximately 0.1 π mm mrad at 400 W.

During the tests we decided to not use the gas injection in the beam line to increase the space charge compensation, as observed for TRIPS [6], because the emittance values were already satisfactory at these current levels.

Figure 7 shows one of the worst emittance plot (ε_N=0.174 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.

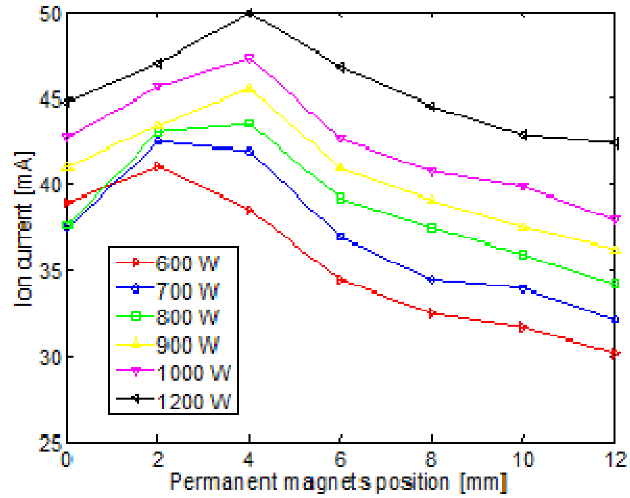

Figure 3:Total beam current vs. permanent magnets position for $P_{source}=2.3 \cdot 10^{-5}$ mbar and V_{ext}=60 kV.

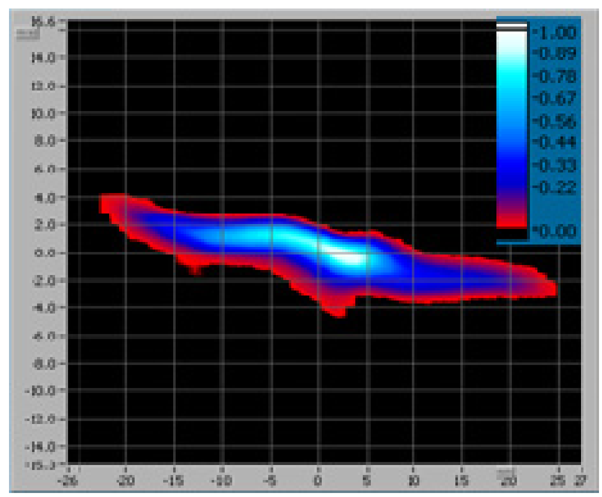

Figure 4: Beam emittance measurements ($P_{source}=2.3 \cdot 10^{-5}$ mbar, I=42 mA, ε_N=0.143 π mm mrad, P_{rf}= 1000 W and V_{ext}=60 kV).

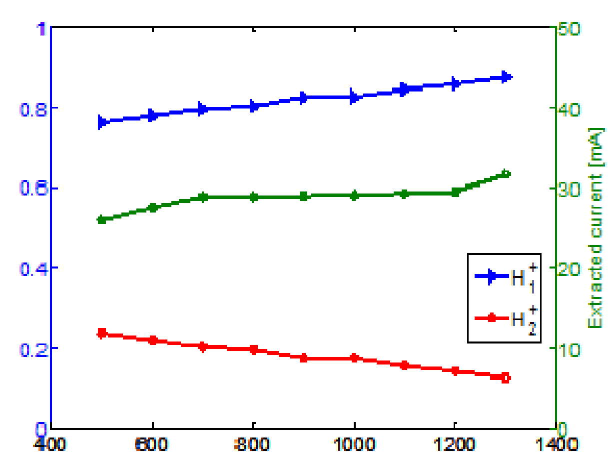

Figure 5: Proton fraction and extracted beam current vs microwave power for P_{source}=1.5•10-5 mbar.

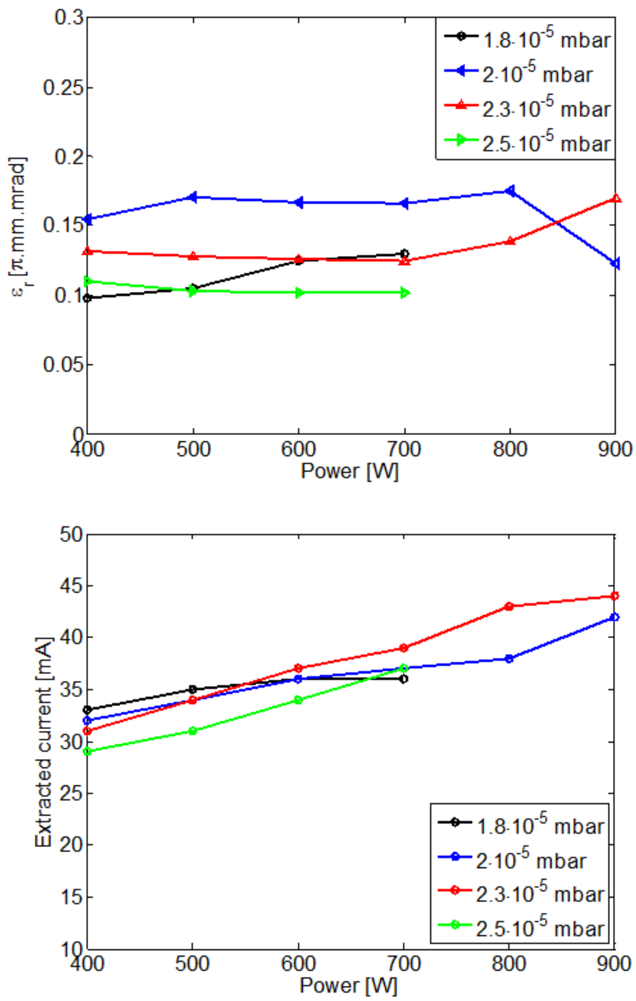

Figure 6: Variation of beam emittance at 60 kV for different pressure values (top). Extracted current at 60 kV for different pressure values (bottom).

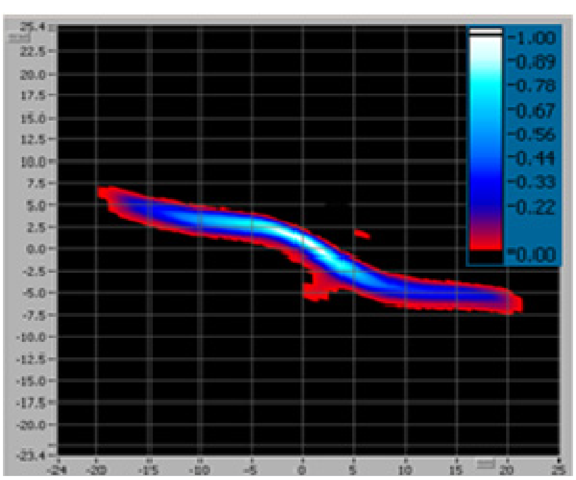

Figure 7: Proton beam emittance measured (P_{source}=2.3•10^{-5} mbar, I=42 mA, ε_N=0.174 π mm mrad, P_{rf}= 900 W).

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, according to the R&D developed at INFN-LNS in the frame of the NTA-HELIOS experiment. A particular emphasis will be given to 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, and to the limitation of the emittance growth which may occur in the LEBT.

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

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REFERENCES

[1] F. Maimone et al, “JACoW, A Service to the Accelerator Community”, EPAC’08, Genoa, June 2008, MOPC151, p. 430 (2008); http://www.JACoW.org.
[2] F. Maimone et al, Proc. of 23rd Symposium on Plasma Physics and Technology, Prague, Acta Tecnica CSAV 53 (2008) 333.
[3] L. Celona et al, Rev. Sci. Instrum. 71 (2000) 771.
[4] R. Gobin et al, Rev. Sci. Instrum. 77 (2006) 03B502.
[5] R. Gobin et al, Rev. Sci. Instrum. 75 (2004) 1414.
[6] L. Celona et al, Rev. Sci. Instrum. 75 (2004) 1423.