Results of SPES Source Improvements

E. Fagotti\textsuperscript{1,2}, A. Palmieri\textsuperscript{2}

\textit{1 Consorzio RFX, 2 INFN Laboratori Nazionali di Legnaro}

INTRODUCTION

The first time step in SPES project is the use of an intense proton source and RFQ cavity to accelerate a 35 mA dc proton beam up to 5 MeV for Boron Neutron Capture Therapy application \cite{1}. SPES RFQ has a nominal transmission above 95\% for input beam emittance less than 0.2 \(\pi\)-mm-mrad \cite{2}. If we take into account an operational transmission of 90\% for the RFQ and 98\% for the LEBT \cite{3}, at least 40 mA proton beam must be extracted from the source. Both current and emittance requirements are achieved by TRIPS source developed by LNS in the framework of the TRASCO project. The source is a high current microwave discharge ion source. Its goal is the injection of a minimum proton current of 35 mA for an operating voltage of 80 kV in the following RFQ, with a rms normalized emittance lower than 0.2 \(\pi\)-mm-mrad and with a reliability close to 100 \% (few failures per year).

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{Misaligned beam seen from the diagnostics box viewport.}
\end{figure}

Source was transferred and installed at LNL \cite{4} and the first tests to characterize extracted beam, started at the end of 2006. The line used for testing the source was simply a diagnostics box and an end-cup without any focusing system. At the beginning the extracted current was measured as the absorbed current of the 90 kV power supply. This was very close to the beam current, considering that absorbed current without beam load was only 0.72 mA. A 70\% of the extracted current at the end cup location was measured. The intensity reduction was due to the fact that a significant fraction of the beam was lost on a water cooled collimator installed in front of the end cup. This loss was caused by a strong beam misalignment and an high beam divergence (see figure 1). Besides, high voltage (HV) column experienced many sparks making the beam characterization procedure very difficult.

The main cause for sparks in the source was identified in the magnetic field protrusion in the unshielded HV column.

B-FIELD REDUCTION IN THE HV COLUMN

The microwave proton source requires an 875 G axial B-field in order to generate an electron cyclotron resonance (ECR) for plasma production. Beam current is sensitive to axial magnetic field tuning \cite{5}. One of the best current-production modes is obtained with the proton-source solenoids separated by 9.2 cm and with a current of 127 A each. By using these parameters, magnetic simulations foresee the resonance positions on the surface of the two Boron Nitride disks used for current enhancement.

The proton beam is coaxially extracted with magnetic field, thus relatively high B-fields extend throughout the HV column. Any electron with a velocity transverse to the B-field would undergo cycloidal motion. Its path length up to the anode surface would be greatly enhanced thus allowing higher residual gas ionization in the region of the HV column. This effect is particularly evident in the region between plasma electrode support (80 kV) and puller electrode (35 kV) where electric and magnetic field are both perpendicular to each other and to the electron motion. This effect may be suppressed by changing the stainless steel plasma electrode support with a ferromagnetic one. A POISSON \cite{6} model for the B-field reduction shows a 93\% B-field reduction at 7.0 cm radius and 78\% at 4.0 cm radius \cite{7}. Magnetic shielding of HV column implies a new optimization for the position and current of source solenoids. The presence of ferromagnetic shielding near the extraction point greatly increases the longitudinal magnetic field gradient. Therefore, if one chooses to locate both the resonances on the BN disks, a reduction of the resonance bandwidths and consequently of the surface interested by resonance occurs (see figure 2). Experimentally this configuration resulted in a poor current production. The resonances pattern that resulted extremely
fruitful for current production is shown in figure 3. In this case, only the BN disk located at injection of the plasma chamber is interested by resonance, but the bandwidth is six times larger than the other case.

FIG. 2: Calculation of the proton source magnetic field with iron shielding. Resonant magnetic field of 875 G at 2.45 GHz may be located at the plasma chamber injection and extraction adjusting solenoids position and current. In this case, resonant zone are located on BN disk surface.

With this solenoids setup, the same current performance of the unshielded configuration was obtained. With regards to the sparks problem, the benefits of HV shielding were evident just in the plasma chamber conditioning process. During plasma chamber conditioning and after HV conditioning, column pressure was tested up to 1.2x10^{-4} mbar in the nominal voltage configuration. No discharge phenomena were encountered in the process. In the unshielded configuration, vacuum limit to avoid sparks was 1.3x10^{-3} mbar.

Cause to the sparks problem, the length of the gap between plasma and puller electrodes was increased in order to reduce electric field. This was the principal reason for beam divergence increase at extraction.

The success of the magnetic shielding allowed to reestablish the theoretical gap distance and to greatly reduce the beam divergence at extraction and consequently the beam dimensions in the LEBT.

CONCLUSIONS

Magnetic field reduction in the HV column allowed to solve the sparks problem and indirectly to reduce beam divergence. With the new alignment system, the beam extraction angle was greatly reduced (see figure 4). Next step will be a long run test to measure beam availability.

FIG. 4: Beam viewed through the diagnostic box viewport after column improvements. Misalignment and beam divergence are strongly reduced.