Design of the SPES-1 LEBT

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I. INTRODUCTION

AXCEL code \cite{1} is used to derive a first estimation of the radius of curvature $r_p$ of the plasma boundary in the ion-source-extraction aperture. Beam is then generated on a spherical cathode with radius $r_p$ and accelerated through the electrostatic fields of the ion source’s accelerating column. Then beam passes through the LEBT (see FIG. 1), which has two magnetic solenoids and it enters RFQ after passing some collimators and an electrons trap. PARMELA code \cite{2} has been chosen for simulation because it allows transporting three different ion types in the electrostatic and magneto-static fields generated with SUPERFISH code \cite{3}. This is a very interesting feature that allows simulating neutralization of $H^+$ and $H_2^+$ beams extracted from TRIPS source.

II. EXTRACTION AND NEUTRALIZATION

Being a t-code, PARMELA is able to simulate transient effects. A consequence is that simulation starts with no beam at all \cite{4}. This means that a long enough stream of $H^+$ and $H_2^+$ ions must be injected to avoid head and tail effects due to the finite longitudinal dimension of the beam as shown in FIG. 2. Moreover time moves faster for $H_2^+$ ions in order to compensate the lower velocity and minimize simulation time.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{LEBT design. The location of five Bergoz dc and ac current transformers and two video camera diagnostics are indicated.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Head effect in beam generation. Cause to this effect, only central part of the beam enters the calculation.}
\end{figure}

At the beginning, $H^+$, $H_2^+$ ions extracted from the source and $e^-$ generated by residual gas ionization move in the electrostatic fields of the column and in the residual magnetic field generated by the source solenoids. This transport allows finding the point where neutralization rises, that is the point where electrons are stopped by negative electrode (see FIG. 3). At this point electrons are suppressed and compensation of 95 \% is assumed. An important feature to be noted is that the outer part of the beam is strongly focused by electrostatic fields. This over-
focalization in conjunction with the presence of high axial residual magnetic field (950 G) creates a dropping in the beam density near the axis as shown in FIG. 4. This drop has to be minimized reducing the residual magnetic field because the evolution of such density perturbation may excite many possible modes of oscillation, some of which may become unstable or resonate with machine structure.

FIG. 3: The negative electrode suppresses the electron current flowing towards extractor electrode at 80 KV.

FIG. 4: Horizontal and radial profile at 4.36 cm from plasma extraction hole.

III. SPES LEBT SIMULATION

Beam is modeled through the whole LEBT. At the exit of extraction column, the extreme part of beam envelope is constituted by particles that experienced non linear forces in extraction process. These particles are eliminated by a halo scraper after 41 cm from extraction and before they are refocused in the beam core by the first solenoid lens. Collimator between the two lenses operates the ultimate current selection. With this collimator it is possible to operate a light cut leaving 33 mA protons current or a heavier one with 11 mA protons left. A collimation chain in front of RFQ completes the modeling process. It is used to increase proton fraction at values greater than 99 %.

PARMELA simulations show that two crucial points for good beam transmission are the line neutralization and the solenoids non-linear effects. Recent neutralization measurements on TRASCO-SPES provisional line at LNS, demonstrate that electrons generated when part of the beam hit the pipe are sufficient to create good compensation even without gas injection [5]. This is a very important result because one of the main disadvantages of using gas injection to increase neutralization is the loss in proton transmission due to bad vacuum. So beam dynamics and pipe aperture have been optimized to have a selective loss of the H2+ ions through the line. If compensation will be not sufficient, it has been considered the possibility to put some hot cathodes to generate electrons [6].

As regard non linear effects, simulations show that rms emittance is very sensitive to beam dimensions in the solenoids field. This non linear effect is even more dangerous if concurrent with neutralization loss at RFQ port. Ions with great radius experience a stronger focalization than other particles and penetrate in the beam core creating a pick in the density distribution when beam recover its full space charge. In this way, effect of space charge force becomes strongly non linear and contribute to emittance increase. To minimize this effect a new design of magnets has been developed. With these improvements, rms normalized emittance at match point is reduced to 0.08 mm-mrad.

IV. CONCLUSIONS

PARMELA validate the old LEBT design defined using PARMTEQM code [7] and gives important information on beam distribution and compensation. Utilization of SUPERFISH simulated solenoids fields instead of hard edge approximation, allows investigation of emittance increase due to field aberration. This procedure results a powerful tool to find optimum magnets design.