DESIGN OF THE SPES-1 LEBT

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Abstract

The low-energy-beam transport (LEBT) system for the SPES-1 accelerator transports the beam at 80 keV and 30 mA from the ion-source TRIPS [1] to the TRASCO RFQ entrance. A second mode of operation corresponding to 10 mA current is also foreseen. The code PARMELA [2] performed these simulations of the beam transport through the LEBT. This code is used to transport H+ and H2+ in the electrostatic fields of the ion-source extraction, in the magnetic fields of both the source and the solenoid lenses and under space charge and neutralization influence.

INTRODUCTION

AXCEL code [3] 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 goes through the LEBT (see Fig. 1), which has two magnetic solenoids and arrives at RFQ input after passing some collimators and an electrons trap. PARMELA code has been chosen for simulation because it allows transporting three different ion types in the electrostatic and magneto-static fields generated with SUPERFISH code [4]. This is a very interesting feature that allows simulating neutralization of H^+ and H_2^+ beams extracted from TRIPS source.

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 [5]. 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.

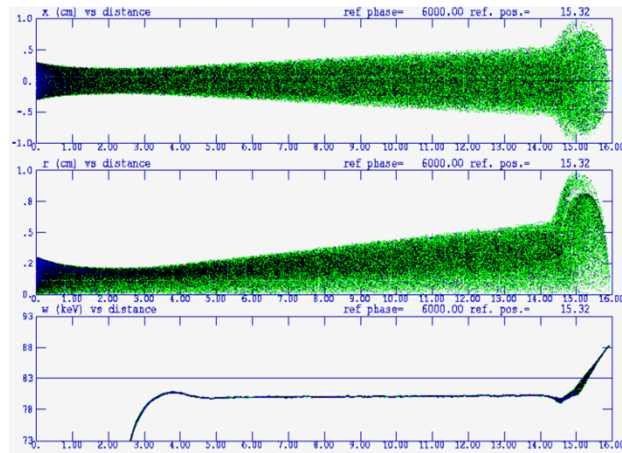

Figure 2: Head effect in beam generation. Cause to this effect, only central part of the beam enters the calculation.

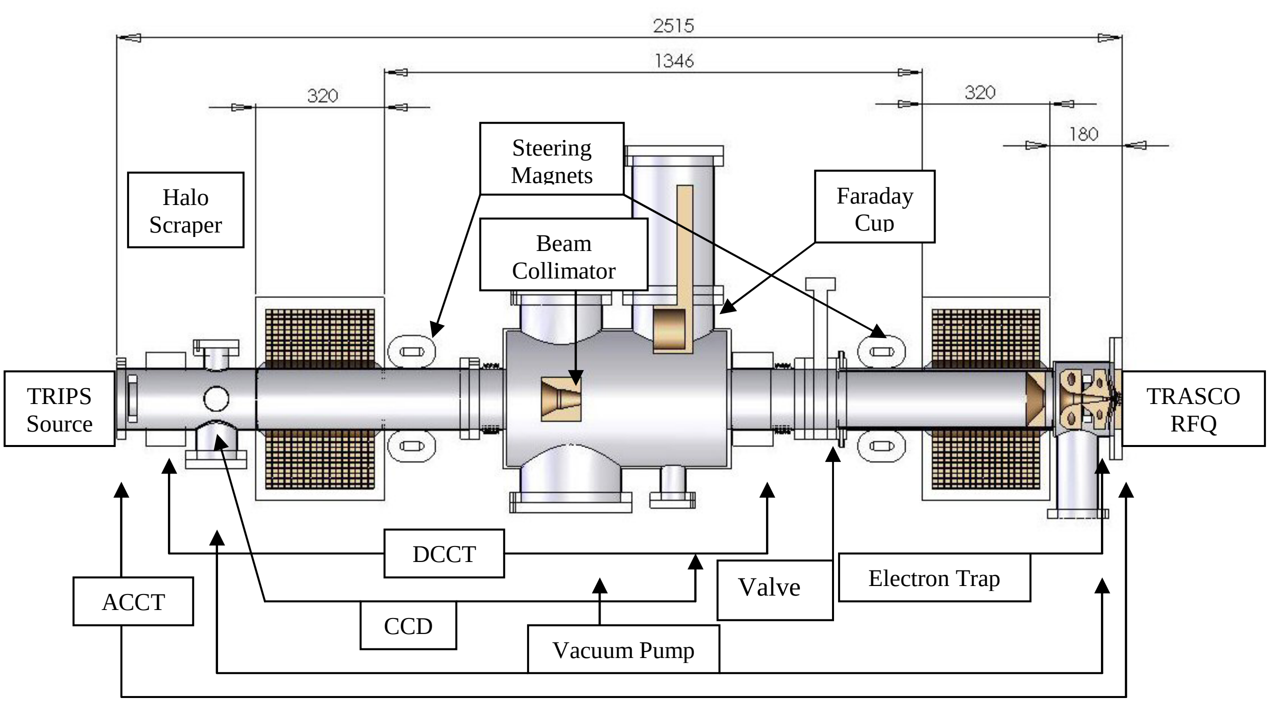

Figure 1: LEBT design. The location of five Bergoz dc and ac current transformers and two video camera diagnostics are indicated.

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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.

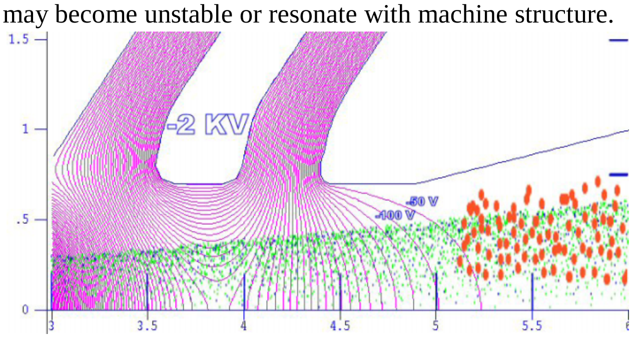

Figure 3: The negative electrode suppresses the electron current flowing towards extractor electrode at 80 KV.

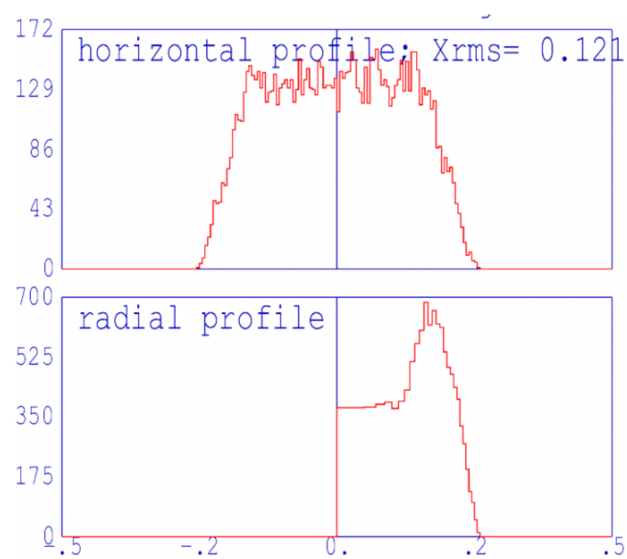

Figure 4: Horizontal and radial profile at 4.36 cm from plasma extraction hole.

SPES LEBT SIMULATION

Beam is modelled 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. This scraper is not cooled because it cuts only a very small beam fraction. This is not the case of the collimator between the two lenses that 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 entrance completes the modelling process. It is used to increase proton fraction at values greater than 99 %.

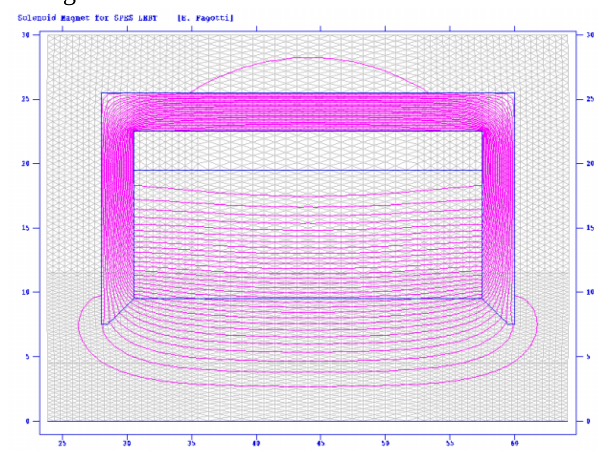

Figure 5: POISSON-calculated solenoid fields.

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 [6]. 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 H_2^+ ions through the line. If compensation will be not sufficient, it has been considered the possibility to put some hot cathodes to generate electrons [7].

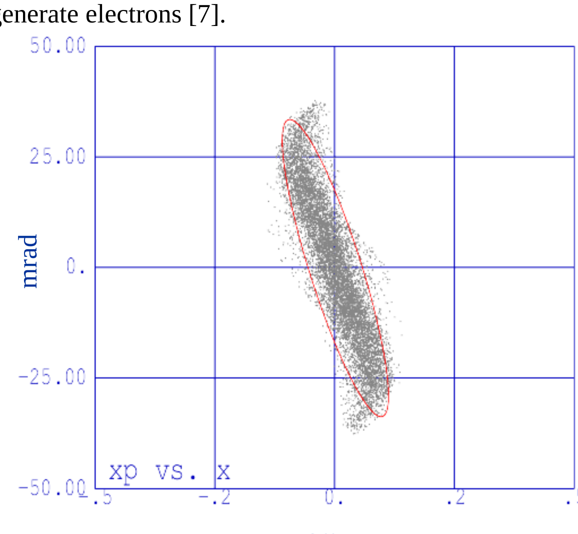

Figure 6: PARMELA-calculated RFQ input.

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 (Fig. 5). Phase-space of the RFQ match point is shown in Fig. 6. With these improvements, rms normalized emittance at match point is reduced to 0.08 mm-mrad.

ELECTRON TRAP

As just said, to maximize proton fraction, a collimator is needed just before RFQ entrance. Collimation process needs some care because of the high power density of the beam in that location. For example, considering all the contaminant ions incident perpendicularly to a 5 mm bore radius collimator, it is simple to find power density values as high as 2 kW/cm^2 [8]. This number raise to 10 kW/cm^2 if we suppose that even the proton beam can intercept collimator. A particular device has being developed to solve this problem and at the same time to prevent electrons from entering RFQ. This device has been optimized to accept up to 20% of the total beam power. In Fig. 7 a schematic design is presented, while in Fig. 8 details of ANSYS thermal simulation are shown. Electrons generated by residual gas ionization have very little energy and it is sufficient to set a -1.5 kV potential on the device central electrode to stop them. Voltage used for trap is much higher than maximum electrons energy for two reasons. On one hand the electrode is at 8 mm distance from beam axis and we need more potential to have an effective field on axis; on the other hand, when electrons are stopped, the beam is completely un-neutralized and the space-charge effect is so high that it tends to attract electrons on the other side of the trap. With the nominal potential, electrons are stopped about 2.5 cm from the RFQ match point.

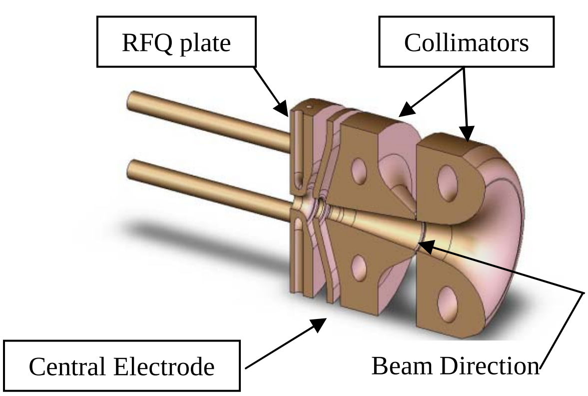

Figure 7: Beam collimator-electron trap device design. The two bars are RFQ stabilization bars.

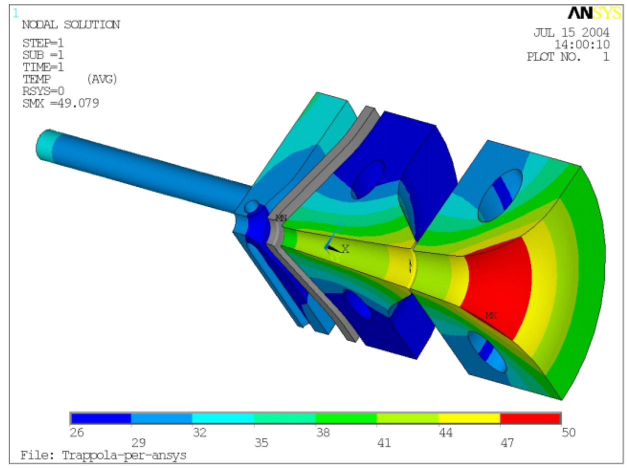

Figure 8: Thermal Analysis of one quarter of electron trap near RFQ port. No beam reaches high voltage electrode, because it is completely shielded by collimator.

CONCLUSIONS

PARMELA validate the old LEBT design defined using PARMTEQM code [9] 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.

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