LEBT BEAM TUNING USING NEUTRALIZED IONS IN THE SARAF FRONT END

Leo Weissman*, Dan Berkovits, Shlomi Halfon, Yariv Yanay**, Soreq NRC, Yavne 81800, Israel

Abstract

The SARAF front end is composed of a proton/deuteron ECR ion source and a LEBT to match the beam to a 4-rod RFQ. The LEBT is consisting of an analyzing magnet, an aperture, three magnetic solenoid lenses and a diagnostic system. The typical operation vacuum, downstream the analyzing magnet, is of the order of 10^{-6} mbar at 5 mA analyzed beam current. In the emittance measurement we identify a beam of secondary-species particles, differently affected by the solenoid and so arriving with a different phase-space profile at the emittance detector. The secondary beam is the result of a charge exchange interaction in which an ion interacts with residual gasses in the beam line, most likely hydrogen gas coming from the ion source, and become neutral. Since the neutral portion of the beam is not affected by the magnetic focusing/steering elements, a none concentric neural and ion beams in the phase-space is a measure of mistuned beam or misalign magnets. These effects were followed by beam dynamics simulation and are used to match the beam to the RFQ.

INTRODUCTION

The Soreq Applied Research Accelerator Facility (SARAF) proton/deuteron linac is currently being commissioned at Soreq NRC [1]. As part of this process transversal emittance measurements were made of the beam coming out of the ECR ion source and passing through the Low Energy Beam Transport section (LEBT). In emittance measurements of the deuterons beam an apparent secondary beam appeared. In the first part of this paper we describe beam dynamics simulations done in an effort to explain these phenomena. In the last part of the paper we show how this phenomena is used to tune the LEBT. All of the measured data and simulations that follow are based on the SARAF LEBT, as described in detail in [2] and shown in Fig. 1.

The section examined begins after a dipole bending magnet that acts as a mass analyzer, allowing only particles of a specific rigidity. At this point a variable-radius (water cooled) aperture is set that allows the current of the beam to be controlled by manipulating the size of the opening. Following the aperture is a magnetic solenoid lens, and further downstream the slit and wire emittance measuring [3] system is placed. The slit and wire (59 cm apart) system yields a snapshot of the phase space of the beam in one transversal dimension. The typical operation vacuum, downstream the analyzing magnet, is of the order of 10^{-6} mbar at 5 mA analyzed beam current.

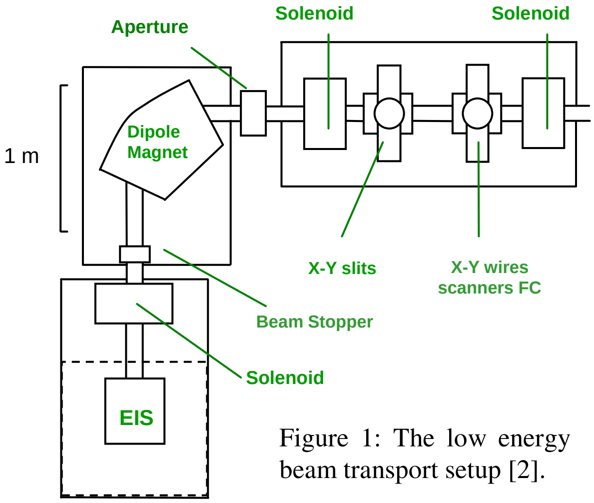

Figure 1: The low energy beam transport setup [2].

CHARGE EXCHANGE PHENOMENON

During deuterons beam characterization, using the slit and wire apparatus for emittance measurements, an additional beam offshoot appears, perpendicular to the main ion beam (Fig. 2). Similar well defined offshoot appears also in other similar ECR+LEBT systems [4]. We identify it to be a beam of secondary-species particles, differently affected by the solenoid and so arriving with a different phase-space profile at the detector. Note that the analysing dipole in our LEBT exclude existence of molecular H_2^+ component of beam as it observed for example in [5].The secondary beam offshoot is likely the result of charge exchange in which the beam interacts with residual gasses in the beam line, most likely deuterium gas from the ion source, exchanging momentum with this neutral gas or creating other charged particles of different rigidity [6].

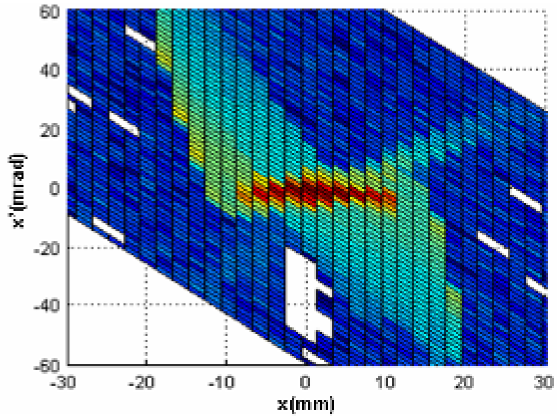

Figure 2: Transversal phase space at emittance measurement of 6.1 mA deuteron beam.

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* Corresponding author weissman@soreq.gov.il
** Today at the Department of Physics, Cornell

For example, for the 20 keV/u protons / deuterons colliding with H_2 / D_2 we calculated an ion neutralization rate of 1%/m/10^{-6} mbar, based on the cross-sections found in [7]. However, such cross-sections generally assume ions are at their ground state, while the hot ECR plasma ions can be excited and their cross section then is not clear and may be higher [8].

For the deuteron beam the most significant interaction seems to be neutral exchange, in which a charged deuteron is incident upon a deuterium molecule and either passes its charge or momentum, creating in the end a neutral particle of the same momentum:

$$d^+(\vec{p})+D_2^0(\vec{0})\rightarrow d^0(\vec{p})+D_2^+(\vec{0})$$

This is the process taken into account in the simulation.

BEAM OPTIC SIMULATION

Our goal with the beam dynamics calculation is to verify the origin of the offshoot. The current data gathered from the slit/wire measurement was taken, as a matrix giving the current *I* as function of the phase space location *(x,x')* (Fig. 2). Using this distribution, made up of roughly 2000 data points, a set of 50,000 – 100,000 macro-particles was randomly created. The *y* phase space was generated with the same parameters of the *x* phase space distribution.

The data presented in Fig. 2 is composed of two beams essentially, the ions and the neutral particles. While the slit/wire system cannot separate these particles, we manually identified the offshoot as the neutral beam, and removed it by hand. This creates the deuteron-only beam shown in Fig. 3, which was then used as input for simulation. Roughly 3% of the particles were removed in this manner, giving us an idea to the exchange rate of this process. Then, the beam dynamics algorithm was used to transport the beam back to the dipole exit and then to run forward, however this time including a neutral exchange effect (Fig. 4).

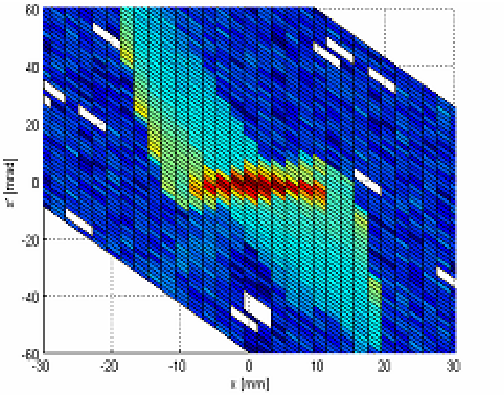

Figure 3: Measured deuteron beam without the neutrals. See details in Fig. 2.

We can clearly see the creation of the same offshoot that had been removed, with the same angle seen in Fig. 2. This verifies our initial assumption and shows the offshoot is indeed a secondary neutral beam. Removing the 3%/m neutrals the measured ion norm rms transverse emittance decreases from 0.29 to 0.25 π mm mrad.

There is a difference between Fig. 2 and Fig. 4 in the position of the offshoot, showing only to the top right in the measured emittance but also to the bottom left in the simulation. This can be explained by misalignment of the solenoid. Alignment manipulation in the simulation moves the location of the offshoot compared to the main beam. This effect is used to tune beam in the LEBT.

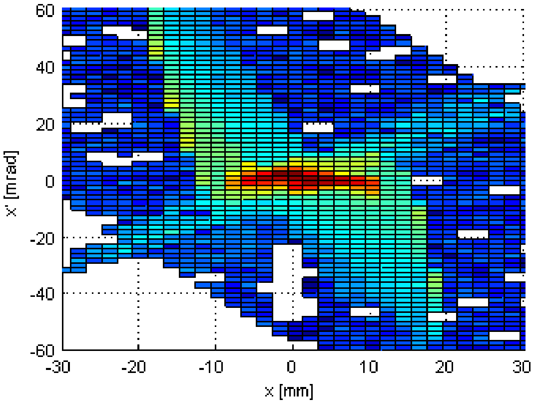

Figure 4: Simulation result of 6.1 mA deuteron beam. See details in Fig. 2.

LEBT TUNING WITH NEUTRALS

The emittance measurement gives only a snapshot of ion distribution in the phase space. This snapshot is done in the plane of the slits. On the other hand the neutral component is originated from the charge-exchange reaction with ion beam in the beam line section between the dipole and the second solenoid. The neutral component is not affected by the solenoid field, therefore it inherits information on the ion beam in that section. For example, it is seen in Fig. 2 that the neutral component is not centred in the phase space as the ion one. It indicates that the ion beam was off axis and had non-zero average angle downstream from the slits plane. This is on contrary to the simulations results where the ion beam was centred along the beam line (Fig. 4).

For well aligned beam the neutral component has to be well centred on the phase space diagram as well as the ion one. Thus, one can exploit the neutral component signature for verification of the beam alignment.

An example of such study performed with proton beam is presented in Fig. 5. In this example we were trying to establish the optimum value of the dipole magnet field. In order to enhance the neutral component a controlled helium gas leak was introduced in the LEBT dipole region. The pressure value was of the order of 5 10^{-6} mbar. The field of the second solenoid was increased intentionally in order to achieve better separation between ions and neutrals components in the phase space. The electrical beam current measured on FC was 3 mA. The phase distributions in x-x' and y-y' plane was measured as a function of the dipole current value. All other LEBT component parameters were kept constant.

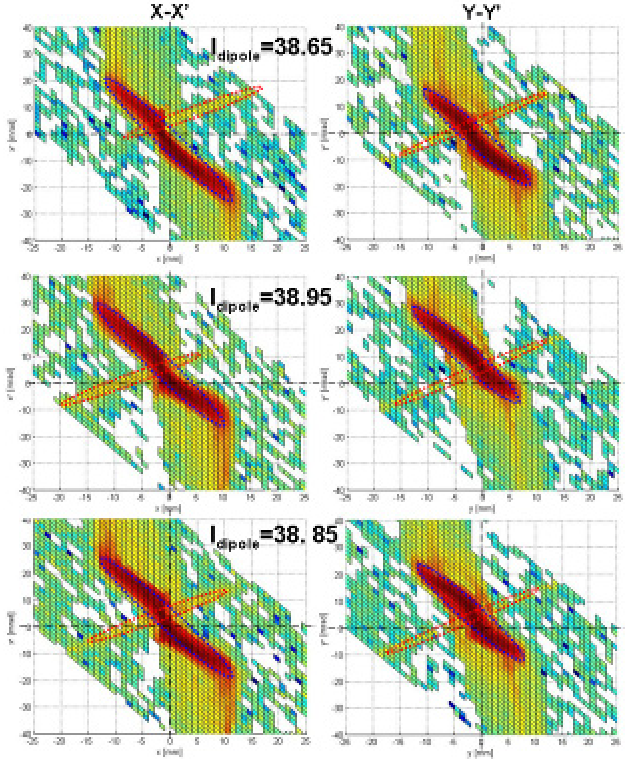

Figure 5. Phase distribution in x-x' and y-y' plane is measured for three current values of the dipole magnet (I_{dipole} in A). The ellipses indicating ion and neutral distribution are just to guide eye.

Varying the dipole field moves beam in the horizontal plane. However the effect of the solenoid lead to migration of the ion components in the both x-x' and y-y' phase planes. On the other hand the neutral component is not affected by the solenoid and undergoes change only in the x-x' plane. One can observe from the figure that the best distribution achieved for the dipole current of 38.85 A. For this current value the neutral component in the slit plain, and hence, the ion component in the section between the dipole and the second solenoid is well aligned. The ion component, e.g. the beam in the slit plain is also well centred. So one can assume the beam in whole LEBT section is well aligned

CONCLUSION

We tried to achieve better understanding of the measured phase distribution. Beam optics simulation confirms that the offshoot observed in the measurements is due to neutral component originated in the section after the dipole. The observed neutral component can be exploited for verification of beam alignment.

More studies of neutralised beam component will follow.

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