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BEAM DYNAMICS OF THE FIRST BEAMS FOR IFMIF-EVEDA RFQ COMMISSIONING

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Abstract

The installation of the IFMIF-EVEDA RFQ, MEBT, LEBT, source and beam dump was completed in September 2017. The beam dynamics of the first beams for the IFMIF-EVEDA RFQ commissioning is presented hereafter. The paper topic is focused on the simulated response of the LEBT RFQ and MEBT complex during the voltage characterization of the RFQ.

INTRODUCTION

The Linear IFMIF Prototype Accelerator (LIPAc) is a high intensity deuteron linear accelerator [1]; it is the demonstrator of the International Fusion Material Irradiation Facility (IFMIF) machine within the Engineering Validation Engineering Design Activities (EVEDA) scope. It is presently in an advanced installation phase at Rokkasho under the Fusion Energy Research and Development Directorate National Institutes for Quantum and Radiological Science and Technology (QST), in the prefecture of Aomori, Japan. LIPAc has been designed and constructed mainly in European labs. It is composed of an injector delivered by CEA-Saclay [2,3], a RFQ [4] designed, manufactured and delivered by INFN on April 2016, a superconducting Linac designed by CEA-Saclay [5], RF power, Medium and High Energy Beam Transfer line (MEBT) and a high power Beam Dump supplied by CIEMAT [6]. The coordination of the European activities is managed by F4E and, on Rokkasho site, the Project Team supported by QST is responsible for integration. The beam that will be produced will be a 125 mA CW D+ beam at 9 MeV after the SRF cavities, delivered onto the high power beam dump. Because of the large power deposition, several commissioning stages were foreseen, each one involving a specific part of the machine.

The next commissioning stage will involve the injector source, the RFQ and the MEBT with a low power beam dump in pulsed mode, up to 0.1% DC. Due to the potential damage even at low DC that may come from the deuteron beam, it was decided to inject a low current proton beam of 7-9 mA at 50 keV, in order to avoid large power deposition and to maximize the RFQ acceptance with respect the input mismatch. The nominal D^+ input current to the RFQ is 135 mA.

This paper presents the beam dynamics studies performed in order to foreseen the behaviour of the RFQ and MEBT with this low current beam. The voltage characterization for different Courant-Snyder parameters of the beam were studied to identify the main characteristics of the beam.

BD CHARACTERIZATION

Injector Input

The source extraction was designed for a maximum 155 mA deuteron total current beam at 100 keV (D^+, D_2^+), extracted from an extraction hole of the plasma electrode of 6 mm radius. In January 2018, we tested several configuration at different proton currents at 50 keV, in order to test the best extraction conditions, reducing the extraction hole down to 3 mm radius.

The results, in agreement with simulations and calculation, consisted of a beam of 13 mA total extracted current (proton and molecular hydrogen ions) with approximately 7-8 mA proton current. Figure 1 shows the simulated phase space at 20 cm from the extraction hole of the plasma electrode, performed with AXCEL, of the beam above considered.

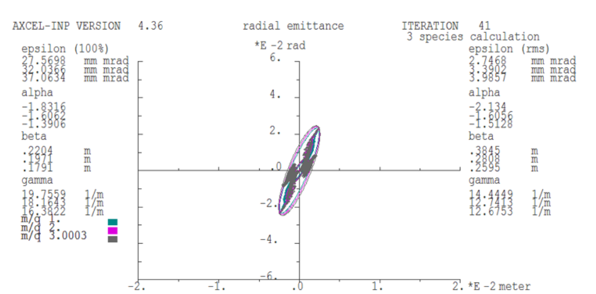

Figure 1: Output at 20 cm from the plasma electrode aperture for 13 mA proton beam.

The divergence of the whole beam is constrained between ±30 mrad, while the dimension is in between ±5 mm. The extraction is behaving like an electrostatic lens decreasing the divergence also of the molecular ions of the hydrogen.

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Since the beam generalized perveance is one order of magnitude smaller with respect the deuteron beam (10^{-3} for D beam and 10^{-4} for low proton current beam), the space-charge effects in the low energy beam transfer line are depressed with respect to the deuteron case.

In such condition, the trace-forward method, applied in previous studies [7], Fig. 2 shows the results for a certain couple of solenoid field, was chosen in order to retrieve the beam evolution along the LEBT up to the RFQ. This step is preliminary with respect the study of the voltage characterization.

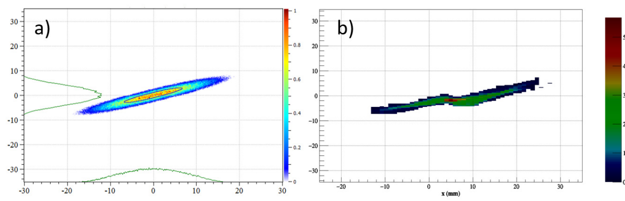

Figure 2: 7 mA proton beam distribution in phase space at the low energy beam transfer line emittance meter position (between the two LEBT solenoids). a) simulated distribution in phase-space, with the same set of solenoid strength b) Measured distribution in phase-space with the same set of solenoid couples. The simulated normalized rms emittance is 0.075 mm mrad, while the measured one is 0.08 mm mrad.

RFQ and MEBT Behaviour

The software used for the transfer lines simulation is TraceWin: the LEBT was implemented in the code with solenoid field-maps; the space-charge compensation trend along *z* was inserted from a WARP simulation. The RFQ was modelled with TOUTATIS code. The RFQ model includes the measured geometry of the cavity [8] and the voltage profile from bead-pull measurements were also implemented in the code [9]. Figure 3 shows the reconstructed macroparticle density along the accelerator with respect the beam axis for the matched beam. Once the nominal solution is retrieved, it is possible to study the voltage characterization of the RFQ.

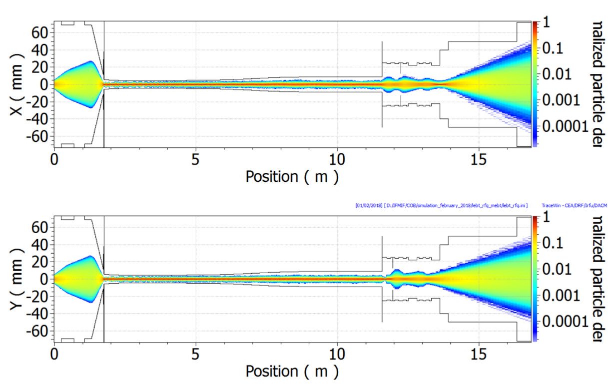

Figure 3: Macroparticle densities with respect the beam axis, starting outside the extraction column and up to the LPBD.

Figure 4 shows the voltage calibration of the RFQ with respect to different input mismatches. The transmission is calculated looking at the RFQ input current, measured by an ACCT, at the RFQ output current, measured by another ACCT at the RFQ exit and at the end of the line, at the low power beam dump, equipped like a Faraday Cup. The MEBT quadrupoles (one triplet and one doublet) were set as for the matched beam. The first results is that the 7 mA proton beam will be 100% transmitted even with a mismatch of 220%, confirming the RFQ low sensitivity to solenoid fields setting with respect to the 135 mA D^+ case, where a mismatch of 20% can cause more losses than 20%.

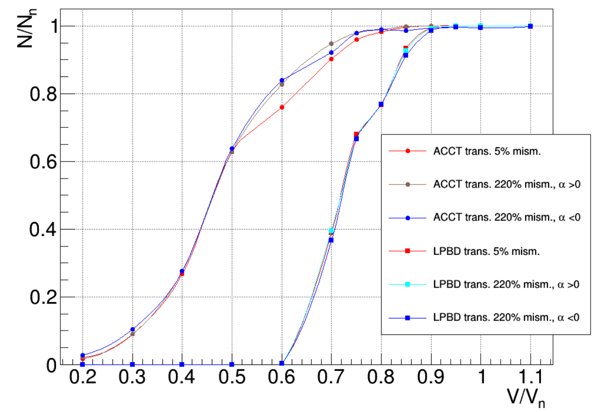

Figure 4: Normalized transmission (N/Nn) with respect to the matched value transmission (Nn) from the RFQ input current (LEBT ACCT) to the output of the RFQ (ACCT) and to the end of the line (LPBD) with respect to different RFQ voltage ratios (V), normalized to the nominal voltage value (Vn). Different curves with respect to different input matching. α indicates a converging or diverging beam at the RFQ input. The different matching was obtained changing the solenoid values in the LEBT model. The difference between the ACCT and the LPBD currents are due to the not accelerated particles, which are not transmitted along the MEBT section due to a sort of energy selection done by the quadrupoles and appropriate placed scrapers.

The effective mismatch can be investigated looking at the second order moment of the beam at the diagnostic emittance-meter position in the diagnostic plate, placed between the MEBT and the LPBD.

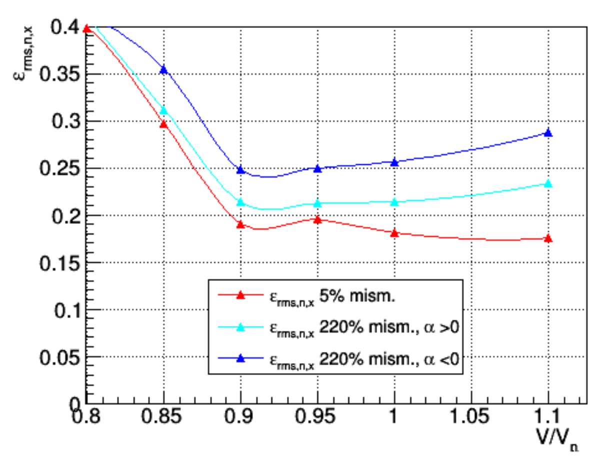

Figure 5: Transverse emittances measured at the end of the MEBT for different RFQ input mismatches.

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Below 0.9 V_n, the differences between the two curve ensembles disappear, therefore it will be difficult to identify what may be the best matched beam.

The effective mismatch can be investigate looking at the second order moment of the beam at the emittance-meter position, in the diagnostic plate, placed between the MEBT and the LPBD.

As shown in Fig. 5, the smallest emittance above 0.9 V/V_n is given by the matched beam at RFQ input, as it is expected.

Effect of Contaminants

Since the 13 mA beam to be injected is a composition different ions (H, H_2 and H_3) and since the extraction system of the source is behaving such as an electrostatic focusing (mass independent), a large part of contaminants will not be cancelled by the injection cone.

Therefore, the transmission will be, in generally, lower than the single species one, because of the contribution of the contaminants. This is shown in Fig. 6, which compares the voltage calibration curve in case of contaminants presence and in case of single species transfer.

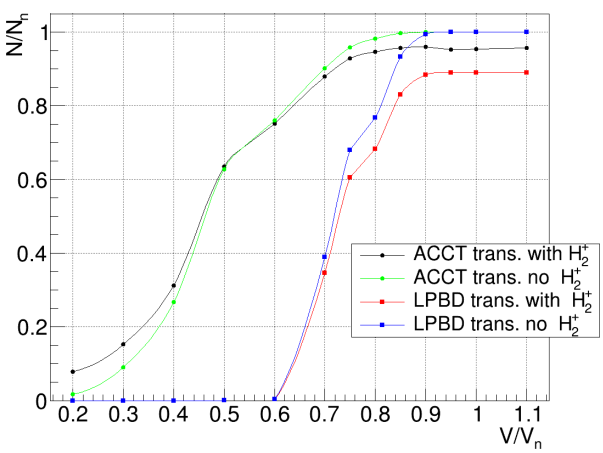

Figure 6: Proton transmission from the RFQ with respect different voltage ratios at the MEBT ACCT and the LPBD. The two curve ensembles are related to the calculations with and without contaminants.

Some number of contaminants survives through the RFQ channel and it can be measured by the output ACCT, even with very low potential. At the first MEBT quadrupole, the wrong energy particles are strongly defocused, causing them to be lost on the MEBT drifts. These not accelerated particles will never reach the LPBD.

This biases the measure of the transmission at the LPBD, and it must be taken into account when contaminant presence is not negligible.

CONCLUSION

The first beam input of IFMIF-EVEDA RFQ has been chosen and deeply studied. Thanks to its robust beam dynamics, it will allow to debug any possible issue of the RFQ in a safety environment. The current of the beam will be then ramp up to 30 mA, in order to study the effect of the growing space-charge term in the accelerator.

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