BEAM DYNAMICS ERROR AND LOSS INVESTIGATION OF THE FAIR PROTON INJECTOR*

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Abstract

The general layout of the 325 MHz, 70 MeV FAIR proton linac is based on three coupled CH cavities and three standard CH-DTL. In combination with the KONUS beam dynamics, this solution allows to achieve all the requirements of the FAIR project in terms of beam intensity and quality, with a reduced number of focusing elements when compared to traditional DTLs.

In particular, the use of long lens free section at higher energies has be carefully investigated in terms of potential beam losses. Random construction mistakes such as quadrupole misalignments and rotation, as well as phase and voltage setting errors can lead to beam losses. It becomes essential to investigate those effects in order to control the emittance growth and to predict the radiation level hazard during beam operation.

According to the result of error investigation, the position of correcting steerers, the mechanical tolerances for the alignment and the maximum allowed phase and voltage oscillations can be defined.

THE FAIR PROTON LINAC

The FAIR proton injector [1] will be used as a dedicated injector for the SIS18. It has to provide at least 35 mA at the final energy of 70 MeV with a repetition rate of 4 Hz. The linac starts with a 100 mA ECR source generating 95 keV protons followed by a Radio-Frequency Quadrupole. At present, a 4-rod RFQ and a Ladder-RFQ are under investigation at the University of Frankfurt [2].At 3 MeV the beam is boosted by three coupled CH resonators to 36 MeV where a dedicated section for diagnostics is installed [3, 4, 5]. Other three single resonators perform the final acceleration to 70 MeV where the beam enters the transfer channel towards the SIS 18.

Both RFQ and CH cavities are operated at the resonance frequency of 325.2 MHz, nine times the basic resonance frequency of the UNILAC complex.

Tab.1 shows the main beam parameters evolution through the DTL section when a 70 mA beam distribution is used at the RFQ output.

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Table 1: Main beam parameters of the FAIR proton linac for a current of 70 mA.

Beam Parameters	DTL Input	DTL Output
Energy (MeV)	3	70
100% norm. RMS X-X' (μrad)	0.23	0.43
100% norm. RMS Y-Y' (μrad)	0.21	0.45
100% RMS $\Delta\phi\Delta$E (keV ns)	1.41	2.65

To investigate the beam losses due to alignment errors and power oscillation an RFQ output current of 80 mA was used. This particle distribution was obtained by tracking the full 100 mA ECR current through a 4-rod RFQ. Non accelerated particles, around 3% of the RFQ output beam, are also included in the simulations. The input and output distribution for the nominal case, i.e, without errors, are shown in Fig.1. Non accelerated particles are shown only in the transversal plane.

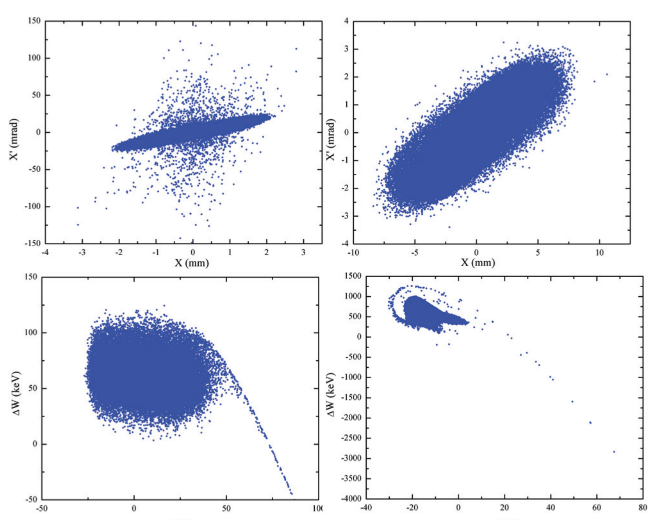

Figure 1: On the left side the horizontal and vertical RFQ output distribution, on the right the corresponding distribution at the DTL exit. Non accelerated particles are shown only in the transversal plane.

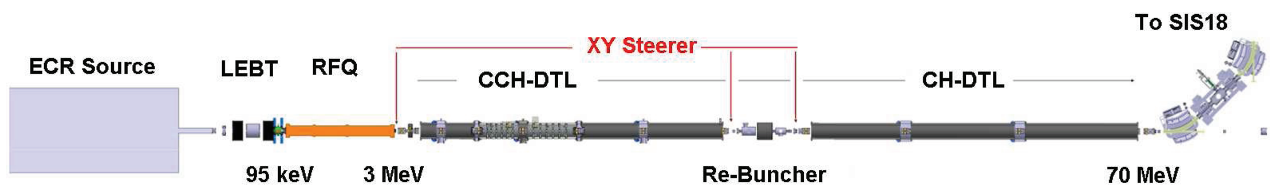

Figure 2: The schematic layout of the FAIR proton linac including the position of the XY steering magnets.

ERROR STUDIES

The error study is performed in the DTL section, i.e. after the end plate of the RFQ. The goal of this investigation is to fix the mechanical tolerances and to evaluate the robustness of the linac against random errors. Those errors includes quadrupole rotation, translation, and variations of operational parameters such as voltage and phase oscillations of the amplifiers. The result loss scenario will be then used to define the radiation shielding inside the linac building.

In a first step, the sensitivity with respect to each single source of error was investigated to set the tolerances for each parameter. Afterwards, all error sources within the given tolerances are added up to evaluate the potential loss profile and the emittance degradation along the linac. Simulations are performed with the LORASR code which was updated to evaluate that specific topic. The implemented errors analysis includes

- Quadrupole translations in the transverse plane;
- Quadrupole rotations in the 3D space;
- Single gap voltage errors;
- Klystron voltages oscillations;
- Klystron phase oscillations;

Quadrupole translations are applied separately to each quadrupole while rotations are applied to the entire triplets used in the KONUS beam dynamics. The errors are randomly generated with a Gaussian distribution cut at 2 σ. In order to obtain a reliable statistical result, 1000 runs were performed for each single error.

Moreover, a steering correction routine was implemented in order to simulate the effect of XY sterrer along the beam axis.

Steering Correction Routine

To improve the capabilities of the error investigation, LORASR was upgraded with a new steering correction routine [7]. In particular, two options have been included in the code.

In the first case no focusing elements are placed between two steerers. In this case, the first steerer corrects the angle so that no displacement occurs at the second steerer position. The second steerer is then responsible for the further alignment of the beam which proceed then parallel to the beam line. The situation is illustrated in Fig3.

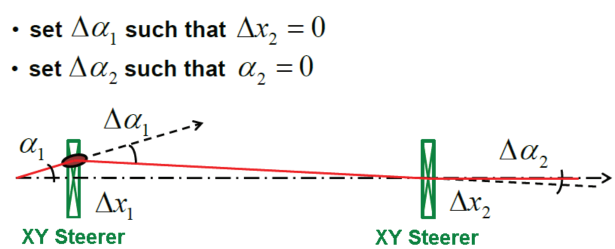

Figure 3: The stainless stems welded into the outer cylinder.

The second case, shown in Fig.4 includes the presence of a focusing element between two adjacent steerers. In this case LORASR corrects only the steering angle which is reduced of a factor two at the location of the second steerer.

At present the correction applies in both transversal plane simultaneously. The possibility to simulate single plane correction will be implemented in the future.

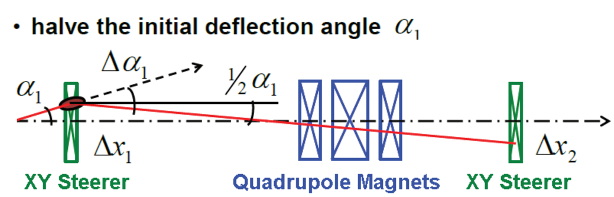

Figure 4: The camera assisted welding operations.

The proton linac includes three couples of XY-steerers, one placed immediately behind the RFQ, and two pairs located in the diagnostics section. Generally, beams coming from RFQ can present an output angle but not a transversal misalignment so that a single pair of correctors is enough.

It is important to remark that, as no steerered beam is assumed in the simulations, the first pair has no impact on the simulations.

Error Analysis

The first analysis was dedicated to fix acceptable upper bound tolerances for each type of error along the CH-DTL. Previous analysis [6] showed that the beam losses are mainly due to quadrupole misalignments of the transversal plane. Secondary contributions comes from the rotational errors and from the oscillation in phase and voltage of the RF amplifiers.

The parameters used for the latest loss investigations are shown below and are in agreement with loss errors per-

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formed on other machines [8]. In particular, the development of adequate control systems for the FAIR and the experience at GSI indicates that rotational error of half a degree and klystron oscillation of 1 % are rather pessimistic. On the other hand, the large experience in cavity tuning allows to set the single gap voltage errors to a maximum value of ±5%.

- Transverse displacements in X,Y: ±0.1 mm ;
- Pitching, yawing and rolling angle: 8.725 mrad;
- Single gap oscillations: ±5% ;
- Klystron voltages oscillations ± 1%;
- Klystron phase error ± 1 degree;
- Number of runs: 1000;
- Number of particles/run: 100000;

The main results of the loss and error investigations are presented in Figs.5-7, where the statistical analysis of the transmission and transversal RMS degradation is presented. In more than 65% of the cases the total transmission remains over 80%, corresponding to 65 mA. Around 3% of losses are due to the non accelerated particles leaving the RFQ. The average transmission of all 1000 runs result also to be higher than 80 %. For a misalignment of± 0.2 mm the average transmission drops down to 60%

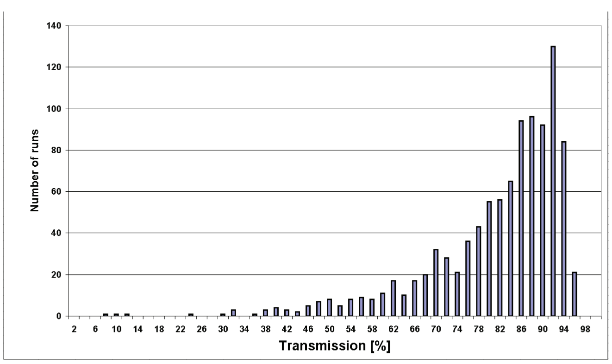

Figure 5: Statistical analysis of the transmission over 1000 runs.

RMS degradation is also acceptable in both planes, where a maximum increase of around 15% can result from the analyzed errors.

OUTLOOK

The loss errors investigations indicates that the design of the proton linac is rather robust against beam losses due to random errors. In particular, the rms degradation remain well within the requirements for the synchrotron injection. The LORASR code was updated with a new correction routine which is able to simulate the effect of correction XY steerers.

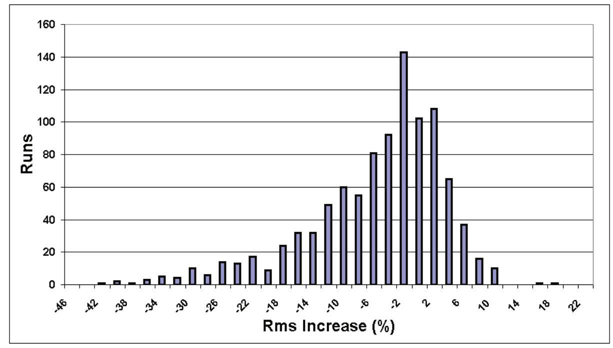

Figure 6: Statistical analysis of the rms emittance in the horizontal plane.

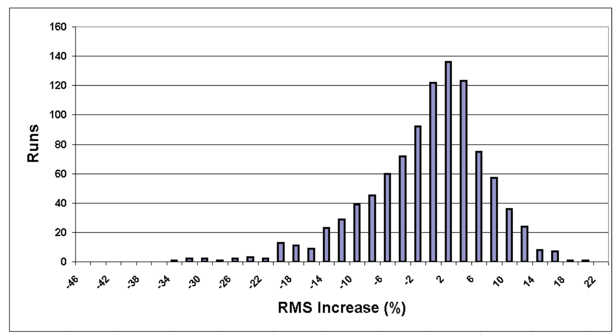

Figure 7: Statistical analysis of the rms emittance in the vertical plane.

At present, only three pairs of XY steerers are planned along the linac, one pair after the RFQ and two pairs at the side ends of the diagnostics sections. Further simulations will evaluate the effect of the introduction of another pairs of corrector placed in the CCH-DTL sections.

ACKNOWLEDGMENT

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