STATUS OF THE BEAM DYNAMICS DESIGN OF THE NEW POST-STRIPPER DTL FOR GSI - FAIR

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Abstract

The GSI UNILAC has served as injector for all ion species since 40 years. Its 108 MHz Alvarez DTL providing acceleration from 1.4 MeV/u to 11.4 MeV/u has suffered from material fatigue and has to be replaced by a new section [1]. The design of the new post-stripper DTL is now under development in GSI. Five Alvarez tanks with four intertank sections provide 100% transmission and low emittance growth. The intertank sections allow for a matched solution and provide place for diagnostics [2]. Simulations along the complete Alvarez DTL were done for $^{238}U^{28+}$ using the TraceWin code [3]. The transversal zero current phase advance is 65° for all tanks. Results of beam dynamics simulations for six different scenarios as well as an error study for the FAIR nominal case are presented.

INTRODUCTION

The existing UNIversal Linear ACcelerator UNILAC at GSI (Fig. 1) serves as injector for the Facility for Antiproton and Ion Research (FAIR), which is under constructions now at GSI [4].

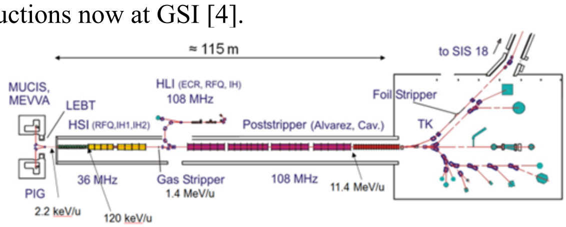

Figure 1: The UNIversal Linear ACcelerator (UNILAC) at GSI.

To match FAIR requirements [5] the UNILAC needs a considerable upgrade. The existing post-stripper DTL suffered considerably from material fatigue during the last four decades and the amount of resources required for its maintenance increases continuously. Replacement by a completely new DTL is due. The beam design parameters of the upgraded UNILAC are listed in Table 1.

Table 1: Parameters of the Upgraded UNILAC

Ion A/q	≤ 8.5
Beam Current	1.76 A/q mA
Input Beam Energy	1.4 MeV/u
Output Beam Energy	3-11.7 MeV/u
Beam Pulse Length	≤ 1ms
Beam Repetition Rate	10 Hz
Rf Frequency	36.136 /108.408 MHz

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STRUCTURE OF THE NEW POST-STRIPPER ALVAREZ DTL

The new Alvarez DTL has a length of 57 m and consists of five tanks with 55, 22, 43, 35 and 31 cells, correspondently. The RF design phase is -30° for A1-A3 and -25° for A4-A5. An optimized drift tube shape increases the shunt impedance [6] and varying stem orientations mitigate parasitic RF-modes [7]. The intertank sections A1-A2, A3-A4 and A4-A5 have a length of 1 m and consist of quadrupoles, one buncher and space between them. These drifts can be filled with other elements (trafo, steerer, grid, probe etc.). The 1st and the 3rd quadrupoles with an effective length of 96 mm are placed partially inside the tank cover. The middle quadrupole is 25% longer. A rebuncher with 0.6 MV is placed behind the 2nd quadrupole. The intertank section A2-A3 consists of a 2-gaps buncher matching the periodic solution between A2 and A3.

BEAM DYNAMICS SIMULATION FOR THE NEW ALVAREZ DTL

Beam dynamics simulations for the new post-stripper DTL were done for $^{238}U^{28+}$ using the TraceWin code. The input distribution is assumed Gaussian, truncated at 3Φ. Input rms emittances were chosen as E_x=E_y=0.175 mm mrad (norm.) and E_z=70 deg keV/u. The behaviour of the beam in the proposed structure was investigated for different zero current phase advances, as without current, as for the current of 16.5 mA. Periodic solutions were found for each case. Finally beam dynamics simulations were done for the transverse zero current phase advance of 65° for each tank. The results of the beam dynamics simulations for the current of 16.5 mA are presented in Fig. 2.

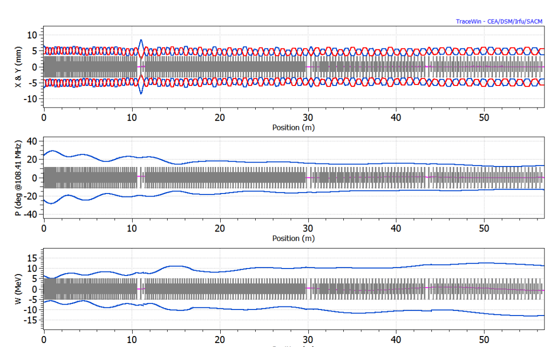

Figure 2: Transverse and longitudinal envelopes along the complete Alvarez DTL.

Table 2: Six Investigated Cases for the New Alvarez

	FAIR	Zero current	Low energy	Larger long. emit.	Smaller long. emit.	Transvers. flat beam
Current, mA	16.5	**0**	**0**	16.5	16.5	16.5
Input ε_x (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.0875**
Input ε_y (rms), mm mrad	0.175	0.175	0.175	0.175	0.175	**0.35**
Input ε_z (rms), mm mrad	0.07	0.07	0.07	**0.14**	**0.035**	0.07
Output energy, MeV/u	11.4	11.4	**3.3**	11.4	11.4	11.4
Transmission, %	100	100	100	100	100	100
$\Delta\ \varepsilon_x$ (tot, 95%), %	7	0	0	7	8	16
$\Delta\ \varepsilon_y$ (tot, 95%), %	7	0	0	10	7	3
$\Delta\ \varepsilon_z$ (tot, 95%), %	10	0.7	1.7	5	11	4

The tune depression at the beginning of each tank is lower than 0.7, i.e. there is considerable space charge. The points at the Hofmann's chart are anyway placed in the stable area (Fig. 3).

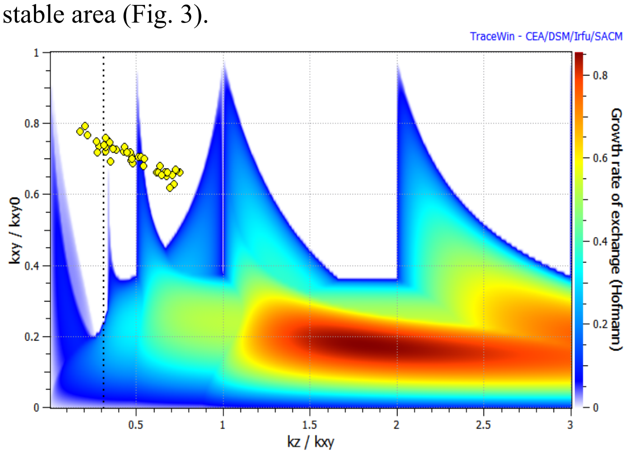

Figure 3: Hofmann's stability plot for the new Alvarez.

BEAM DYNAMICS SIMULATIONS FOR DIFFERENT SCENARIOS

The UNILAC also serves established GSI experiments requiring beam energies close to the Coulomb barrier, i.e. it provides energies in the range from 3.0 MeV/u up to 11.7 MeV/u. For the low energy operation the rf-power of some tanks is switched off.

Other scenarios including twice larger or twice smaller input longitudinal emittances as well as an transverse flat input beam shall probe the design robustness. The results of beam dynamics simulations for six different cases including the FAIR nominal case are presented in Table 2.

ERROR STUDY FOR FAIR NOMINAL CASE

Error studies for the new Alvarez DTL were done taking into account machine and beam errors (Table 3), which are independent and uniformly distributed within the given intervals. All cases revealed 100% transmission. The average additional rms emittance growth caused by the machine and beam errors is about 26%. The spectrum for 1000 runs with 10^5 particles is shown in Fig. 4.

Table 3: Machine and Beam Errors

Quadrupole x,y displacement	± 0.15 mm
Quadrupole x,y,z rotation	± 1°
Gap voltage	± 1%
Gap phase	± 1°
Initial energy	± 0.5%
All three input emittances	± 15%
Input beam mismatches	± 10%
Input current	± 15%

Detailed investigations show that the beam transport along the 1st tank is most sensitive to errors and leads to further emittance growth along the further tanks. Error studies starting from the 2nd Alvarez tank give a mean additional rms emittance growth of 13% (instead of 26%) for the whole Alvarez.

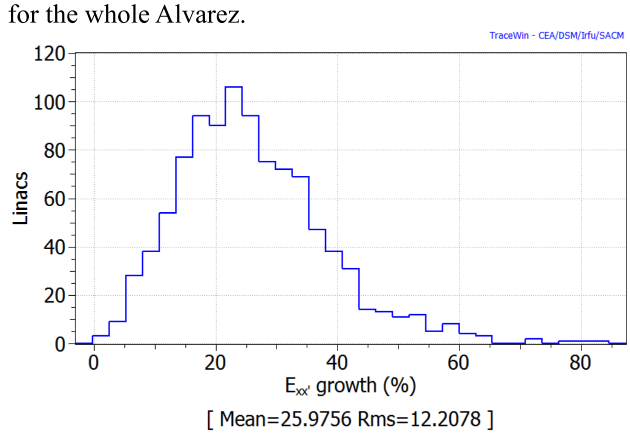

Figure 4: Additional emittance growth in the Alvarez DTL due to machine and beam errors.

The main reason for additional emittance growth is quadrupole rotation around the beam axis (Fig. 5). Decreasing of quadrupole rotation in A1 to ±0.5° while keeping it as ±1° in A2-A5 leads to 13% of mean emittance growth for the whole machine.

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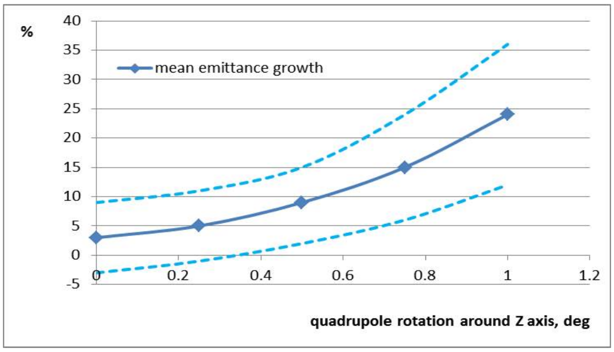

Figure 5: Influence of quadrupole rotation around the beam axis on additional emittance growth; dotted lines show the rms-width of the emittance growth.

BEAM BRILLIANCE BEHIND DTL

In order to estimate the beam brilliance behind the DTL a virtual collimator line was constructed (Fig. 6).

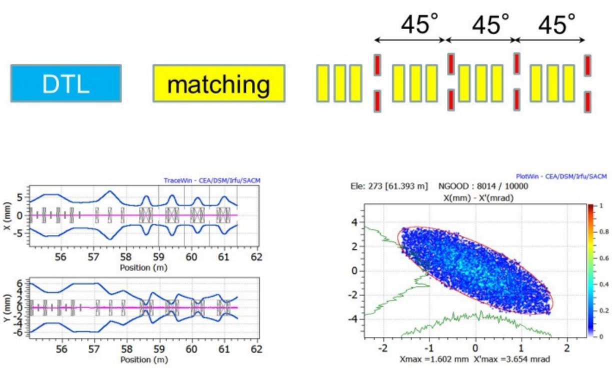

Figure 6: The virtual collimator line behind the DTL.

After four quadrupole triplets and four collimators between them the beam has a well-defined total emittance. The horizontal acceptance of the synchrotron SIS18 to be filled by the DTL is 0.8 mm mrad (total, normalized). Choosing the collimators width such that the collimated beam emittance leaves a margin for additional growth until injection into the SIS18, allows to estimate the current that is expected to be injected within the SIS18 acceptance. This investigation was done without machine and beam errors, as well as with them (Table 4).

Table 4: Beam Current Within SIS18Aacceptance

Emitt. growth until SIS18	Current at SIS18 (without errors)	Current at SIS18 (with errors)
30%	13.2 mA	12.2 mA
10%	14.2 mA	13.2 mA

The position of the data for 30% emittance growth until the SIS18 on the 3D Pareto front [8] is shown on Fig. 7. The current in case of no errors corresponds to suitable losses below 5%. Reduction of the assumed emittance growth to 10% shifts the corresponding points down towards the preferable region.

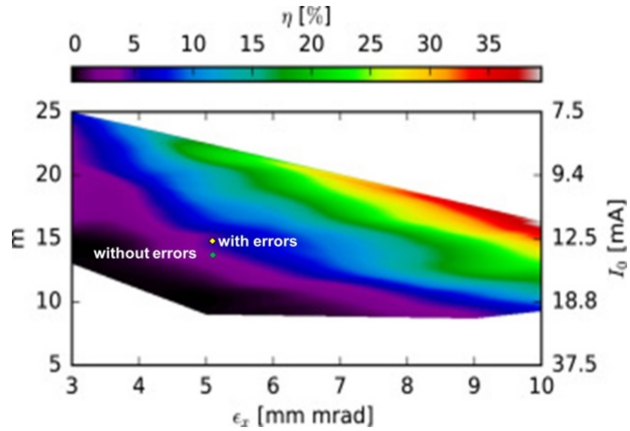

Figure 7: The 3D Pareto front from an optimisation of multiplication factor, loss, and emittance growth [8] with the data achieved behind new DTL assuming 30% emittance growth in the transport channel to SIS18.

SUMMARY

A beam dynamics design of the new DTL was worked out fulfilling the FAIR requirements. Quadrupole rotation around the beam axis in A1 is shown as the most critical factor for additional emittance growth.

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