OPTIMIZATION OF AN IH-CAVITY BASED HIGH ENERGY HEAVY-ION LINAC AT GSI

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Abstract

A new high energy heavy-ion injector (HE-Linac) for the FAIR project was proposed as replacement for the existing post-stripper linac at the GSI UNILAC. Six 108 MHz IH-type drift-tube linac cavities within a total length of about 24 m accelerate the ions (up to U^{28+}) from 1.4 MeV/u up to 11.4 MeV/u. Fast pulsed quadrupole triplet lenses are used for transverse focusing in between the IH cavities. The optimization of the HE linac with respect to the emittance growth reduction is investigated.

INTRODUCTION

The Facility for Antiproton and Ion Research (FAIR) presently under development at GSI in Darmstadt will provide worldwide unique accelerator and experimental facilities allowing for a large variety of research in physics and applied science. The FAIR accelerators will increase the intensity of primary proton and heavy ion beams available for experiments and for the production of secondary beams by up to two orders of magnitude with respect to the existing GSI facility [1]. Besides the realization of the challenging FAIR SIS100 synchrotron, various upgrades of the UNILAC linear accelerator and of the SIS18 synchrotron play a key role to achieve the FAIR design intensities, since the existing GSI accelerators will serve as injection chain for FAIR [2-4]. As design parameters, 15 mA U^{28+} beams at 11.4 MeV/u [2] and 70 mA proton beams at 70 MeV are required for SIS18 injection. A new High Energy Linac (HE-LINAC) is under investigation at GSI in order to replace the existing Alvarez DTL section (Fig.1, Tab.1).

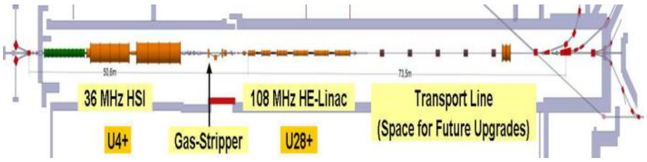

Figure 1: The scheme of the HE linac concept.

Table 1: The Main HE Linac Parameters Based on IH-Cavities

Design ion species	$^{238}U^{28+}$
Design beam current (pulse)	15 mA
Input beam energy	1.4 MeV/u
Output beam energy	11.4 MeV/u
Linac length ca.	24 m
DTL	6 IH-cavities
Cavities length	1.6-3.5 m

The current beam dynamics of the entire HE linac is based on the KONUS concept [5], with an external magnetic quadrupole triplet lens behind each cavity. Particle tracking was calculated with the LORASR code [6], maintained at the Frankfurt University. The existing design (Fig.2) was developed in [7]. The emittance growth through the 6 tanks of HE Linac is about 50%. The goal of these investigations is increasing the beam brilliance as well as smoother envelopes.

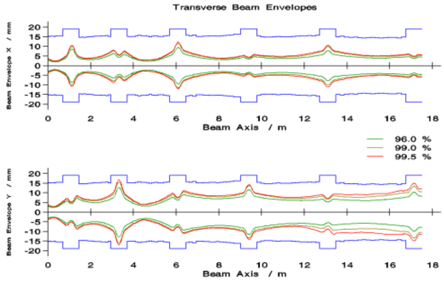

Figure 2: The transverse envelopes through the HE Linac for the existing design.

OPTIMIZATION OF THE HE LINAC

Dependence of the Emittance Growth on the Input Twiss Parameters

The influence of the input Twiss parameters on the emittance growth was investigated for each of the six cavities. The input transverse emittances before the IH1 are 14 mm·mrad and 21 mm·mrad as in existing design. The used beam current is 20 mA. The study was done in two steps, which are illustrated for IH1:

1) Set $\alpha_x=\alpha_y$, $\beta_x=\beta_y$ at the cavity entrance (5 cm before the middle of the 1-st gap). α and β are changed independently from 0.1 to 5.0. The smallest normalized rms emittance growth along IH1 was obtained for $|\beta| \approx 0.5\alpha$, where [β]= mm/mrad.
2) Set $|\beta_x|= 0.5\alpha_x$, $|\beta_y| = 0.5\alpha_y$, [β]= mm/mrad. α_x and α_y are changed independently from 0.1 to 5.0. The smallest normalized rms emittance growth of 5-6% (instead of 11-17% for the existing design) was obtained for $\alpha_x \epsilon [1.5, 4.0]$, $\alpha_y \epsilon [1.0, 4.0]$.

The same procedure was repeated for each cavity. The results of this investigation are presented in Tab.2.

Table 2: The optimum Twiss parameters and corresponding emittance growth (in brackets – the emittance growth for the old design), [β] = mm/mrad.

	IH1	IH2	IH3	IH4	IH5	IH6
|β /α|	0.5	0.7	0.9	1.3	1.6	1.9
α_x	[1.5 ;4]	[2 ; 5.5]	[2 ; 5]	[1.5 ; 4]	[1.5 ; 4.5]	[2 ; 4]
α_y	[1 ; 4]	[2 ; 5]	[2 ; 5]	[1.5 ; 4]	[1.5 ; 4.5]	[2 ; 4]
Emit. growth	**5-6%** *(10-17%)*	**6-8 %** *(17-20%)*	**2-3 %** *(3-5 %)*	**2-4 %** *(3-10%)*	**1-2%** *(2-4 %)*	**1-2 %** *(3-7 %)*

The defined by Tab. 2 values of β, [β] = mm/mrad at the beginning of each IH-tank can be changed on ±20%. The additional emittance growth is less than 1% for each IH-cavity.

For the beam current of 15mA the emittance growth decreases on 1-2% for each tank.

The Improved Design of HE Linac

The improved design aims for defined Twiss parameters before each cavity, keeping the KONUS beam dynamics. For these simulations input Twiss parameters are $\alpha_x=\alpha_y=3.0$, $\beta_x=\beta_y=1.5$ mm/mrad, the transverse emittances are $\varepsilon_x=14$ mm·mrad, $\varepsilon_y=21$ mm·mrad. The matching along the HE Linac was done in order to keep Twiss parameters at the beginning of each IH–cavity as defined in Tab. 2 (β can be changed on ±20%). The triplet gradients and the position of triplets are varied for this. The total length of HE Linac is increased by ~1.4 m.

The transverse beam envelopes are presented in Fig. 3. The envelopes are smoother than before.

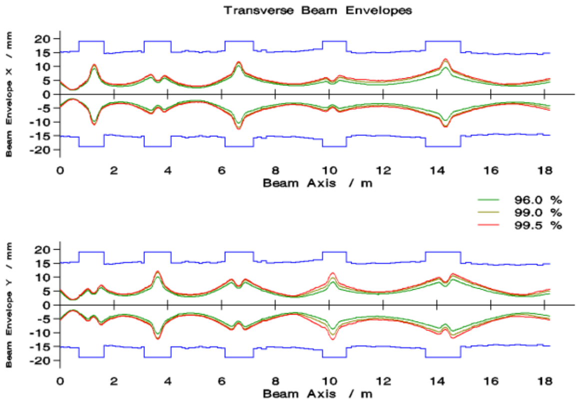

Figure 3: The transverse envelopes through the HE Linac for the improved design.

The emittance growth along the line is about 35% (instead of 50%). Transmission is 92%. The beam brilliance behind the HE Linac is about 1.5 times higher for the improved design (Fig. 4).

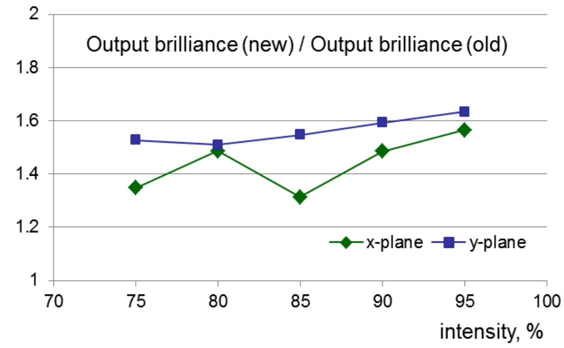

Figure 4: The ratio of the output beam brilliances for the improved and for the old design.

Influence of the Longitudinal Distribution

The assumed longitudinal distribution at the DTL entrance (Fig.5) was generated using the results of measurements for HIPPI project [8].

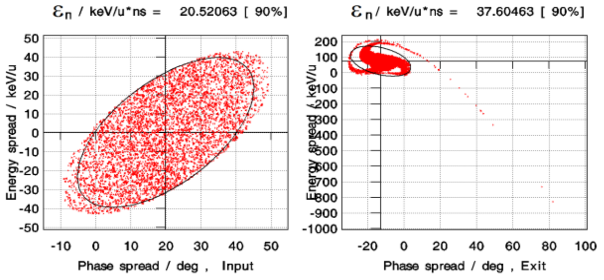

Figure 5: Input and output longitudinal distribution.

Artificial decrease of the longitudinal input emittance to 25% (15 keV/u*ns instead of 20 keV/u*ns) leads to 100% of transmission.

Periodic Solution

A period is defined from the beginning of the cavity (5 cm before the middle of the 1-st gap) up to the beginning of the next cavity.

The solution is called periodic, if α_x, α_y are constant at the beginning of each period and β_x, β_y changes correspondently to the energy growth:

$$(\beta_n / \beta_{n-1})^2 = W_n / W_{n-1}.$$

Since the energy growth is known from the cavities design, the ratio β_n / β_{n-1} can be calculated:

$\beta_2 / \beta_1 = 1.265$, $\beta_3 / \beta_2 = 1.295$, $\beta_4 / \beta_3 = 1.234$,
$\beta_5 / \beta_4 = 1.175$, $\beta_6 / \beta_5 = 1.128$.

As one can see from Tab.2, $\alpha_{x,y} \in [2.0, 4.0]$ satisfy the conditions for the smallest emittance growth in each of the six periods. Since α are constant, the ratios β_n / β_{n-1} can be calculated from the quantities for |β/α| (Tab. 2). They don't correspond to the energy changes. But taking into account, that defined by Tab.2 β can be changed on ±20% without significant emittance growth, the periodic solution β_{period}, corresponding to the energy changes and being inside this ±20% corridor, is found (Fig. 6).

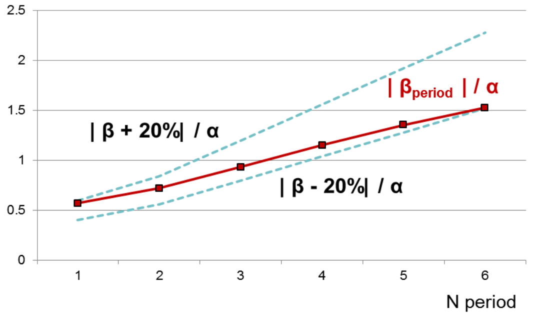

Figure 6: The quantity |βperiod |/α for each period, corresponding to the energy growth, [β] = mm/mrad.

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Now the following algorithm for the periodic solution can be proposed:

- Fix arbitrary α_x and α_y within the interval [2 , 4]
- Calculate β_x, β_y for each tank, [β]= mm/mrad:

|β| (IH1)=0.57 α |β| (IH2)=0.72 α |β| (IH3)=0.93 α
|β| (IH4)=1.15 α |β| (IH5)=1.35 α |β| (IH6)=1.53 α

- Match the beam from the beginning of each IH-tank to the beginning of the next IH-tank, for the chosen Twiss parameters. The triplet gradients and the position of triplets can be varied for this.

Figure 7 shows the example of matching with TRACE 3D code for the input Twiss parameters $\alpha_x=\alpha_y=3.0$, $\beta_x=\beta_y=1.7$ mm/mrad. The distance between cavities should be increased, the total length is 1.4m larger than before. This study is not finished yet.

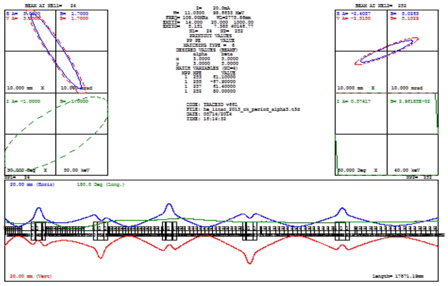

Figure 7: Matching with TRACE 3D code for the input Twiss parameters $\alpha_x=\alpha_y=3.0$, $\beta_x=\beta_y=1.7$ mm/mrad.

Periodic Solution with the Matrix Approach

The following approach is an attempt to create the periodic solution not taking into account an input distribution. We define a period from the beginning of a quadrupole triplet to the next one. F_n is the focal length of the triplet and L_n is a length of correspondent period. Then the conditions of periodicity can be defined by following quantities:

$$F_n = F(\text{triplet})_X = F(\text{triplet})_Y$$

$$F_n / L_n = \text{const.}$$

The focal length can be obtained from the matrix of the triplet. The gradients in each triplet for fixed F/L can be found, but not every combination provides beam dynamics with reasonable losses, even for proper matching of the input distribution. For the preliminary investigation F/L = 0.33 was taken (the mean value F/L for each period and both planes in the old design). A periodic solution for F/L = 0.33 is found (Fig. 8). Transmission for this solution is the same as for the non-periodic solution, but the emittance growth is almost twice higher.

To create a better periodic solution for this definition one could change the geometry of the transport line. But the most preferable approach is the other definition of periodicity (not only triplets but also cavities are included or longer period is considered).

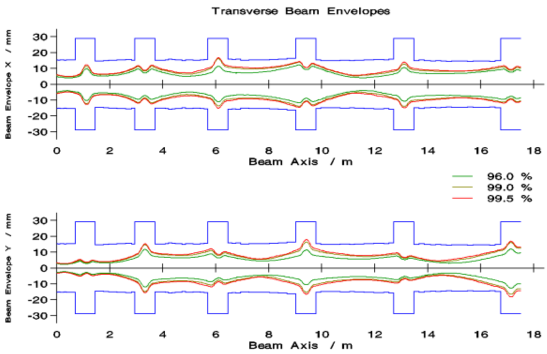

Figure 8: The transverse envelopes through the HE Linac for the design with matrix approach.

CONCLUSION

The optimization of an HE linac based on IH-cavities was done in order to find a periodic solution providing high beam brilliance and smooth envelopes.

Twiss parameters, providing the smallest emittance growth in IH1 – IH6, are found. The solutions have rather wide "corridor" and are independent for x- and y- planes. The matching for non-periodic solution is found and has advantage in transmission and emittance growth with respect to the old design. The beam brilliance behind the HE linac is about 1.5 times higher for the improved design.

The Twiss-parameters for the periodic solutions are defined at the beginning of each IH-tank. The matching from one tank to another must be done precisely. Emittance growth of about 30-35% (instead of 50%) is expected. Oft the distance between the cavities allows integration of diagnostics or another device.

The matrix approach for the periodic solution has to be developed taking into account not only triplets, but also the gaps.

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