CONCEPTUAL STUDY FOR A NEW HIGH ENERGY LINAC AT GSI

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Abstract

The commissioning of the first modules of the FAIR accelerator facility is planned to be completed in 2016. At that time the DTL section of the UNILAC will be more than 40 years old. Different proposals for a new high intensity, heavy ion linac which will replace the ALVAREZ DTL as synchrotron injector are under discussion. This new High Energy UNILAC will be designed accordingly to the advanced FAIR requirements. It will allow for a complete and reliable multi-ion-operation for at least the next 30 years. In the first upgrade step, proposed in the presented design study, four IH cavities will be used to accelerate U^{4+} to 3 AMeV and, after gas stripping, other four IH cavities will cover the energy range up to 11.4 AMeV. In the final step, the injection energy will be increased to 22 AMeV by use of 324 MHz CH-DTL's. The main target is to provide a higher charge state and a higher injection energy to increase the life time of the heavy ion beam inside the synchrotron. The paper presents the beam dynamics and RF investigation for the first stage.

INTRODUCTION

The FAIR accelerator facility, under development at GSI in Germany, requires a massive upgrade of the existing GSI accelerator complex. The existing UNILAC is required to provide short beam pulses (100 μs) characterized by high beam current and rigidity. At a duty factor of 1 % the main goal is to deliver at least 15 mA of U^{28+} for the injection into the SIS18 synchrotron [1].

As the UNILAC was put in operation in 1975, it will be more than 40 years old when the commissioning of FAIR will start. This opens serious concerns about its reliability, especially considering that FAIR will run at least for the following 30 years.

Moreover, the UNILAC magnets can be operated only in DC mode, which makes the machine inefficient in terms of short pulse operation. This represents a flexibility limitation as no modulation will be possible when different ions have to be accelerated from pulse to pulse.

For those reasons a conceptual study for the replacement of the DTL section of the UNILAC is in progress at GSI. This paper presents a solution based on H-mode cavities where the new linac will accelerate a higher Uranium charge state to a higher synchrotron injection energy.

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UNILAC UPGRADE: THE NEW HE-LINAC

As shown in Fig.1 the UNILAC consists of two main sections, the 36 MHz High Current Injector (HSI) and the 108 MHz Alvarez DTL. The HSI delivers a 1.4 AMeV beam which, after the gas stripper and the charge separation section, is accelerated in the five DTL cavities up to 11.4 AMeV. A fine energy tuning can be performed in the single gap resonators before the injection into the synchrotron.

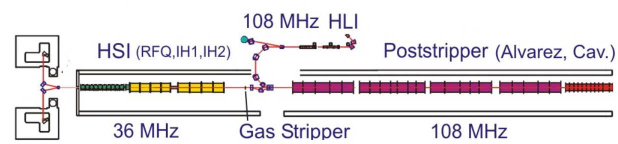

Figure 1: The 11.4 AMeV heavy ion UNILAC accelerator at GSI.

The FAIR program requires a primary U^{4+} beam from the HSI while, after the gas stripping, U^{+28} will be selected for the further acceleration. The acceleration of U^{28+} requires a high accelerator voltage in the DTL and in the SIS18. It also results in high losses in the SIS18 due to charge exchange processes in the residual gas [2, 3]. For that reason, it would be preferable to select a higher charge state for acceleration in the poststripper section. Fig.2 shows that an increase of the beam energy to 3 AMeV makes possible the production of U^{38+}. For this reason, the first upgrade consists in the increase of the prestripper energy to 3 AMeV.

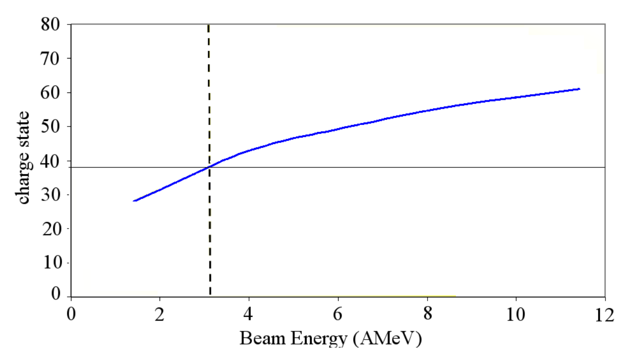

Figure 2: The Uranium charge state after gas stripping as a function of the primary beam energy

To cover the energy range from 1.4 AMeV to 3 AMeV the proposed solution considers the use of four IH cavities operated at 108 MHz. The very high shunt impedance of that kind of cavities allows to cover that energy range

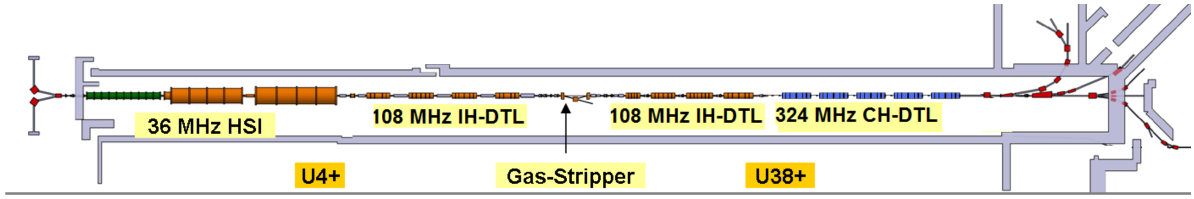

Figure 3: The proposed first upgrade step of the new HE-LINAC at GSI.

within a shorter length when compared to any other solution based on Alvarez DTL. No quadrupole magnet needs to be installed inside the drift tubes due to the KONUS beam dynamics [6] and, at the same time, the power demands will be much lower. The first upgrade step is shown in Fig.3. The prestipper energy will be increased up to 3 AMeV while the gas stripper and the charge separation section will be dismounted and simply reassembled in the new location. The phase spread increase due to the frequency jump from 36 to 108 MHz will be compensated with a powerful buncher mounted at the exit of the HSI.

The Alvarez DTL will be then completely replaced by H-mode cavities as well. At present the proposal is to use other four IH cavities to cover the existing UNILAC energy of 11.4 AMeV. CH cavities at 324 MHz will then be used to perform the last acceleration to an increased injection energy of $\approx$ 22 AMeV.

The choice to increase the injection energy into the synchrotron is a direct consequence of the increase of the accelerated charge state of Uranium. In fact, for the SIS18 the tune shift

$$Q \propto N\frac{q^2}{A}\frac{1}{\beta^2\gamma^3} \qquad (1)$$

is $\approx$ 0.51 for 15 mA of U^{28+} at 11.4 AMeV, but the increase of the charge state from +28 to + 38 corresponds to an increase of Q of 85 %. Assuming 20 mA at 22 AmeV, the corresponding tune shift for U^{38+} will be $\approx$ 0.48 thus fully compensating the increase of the charge state. Moreover, an increase of the injection energy should also correspond to a decrease of the emittance ($\epsilon \propto 1/\beta$).

Beam Dynamics: Pre stripper section

Beam dynamics calculations were performed assuming a 20 mA U^{4+} beam at the exit of the 36 MHz HSI. The A/q ratio was fixed at 60. Particle tracking was calculated with the LORASR code [4], developed at the Frankfurt University, while input emittances were derived from the design output particle distribution of the HSI [5]. Input emittances are shown in Fig.4.

Immediately at the exit of the 36 MHz HSI a powerful six gaps 108 MHz bucher will compensate the phase jump and match the beam for the acceleration inside the H-mode cavities. Transversally, the beam will be focused by two doublets which are already installed in the existing beam line. Four IH cavities are used for the main acceler-

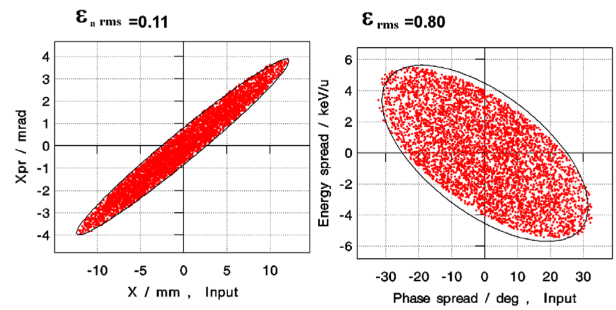

Figure 4: The input emittances of the new HE-Linac

ation. Beam dynamics, as usual for those kind of cavities, will be based on a KONUS focusing scheme, with a long triplet mounted at the exit of each cavity. In fact, the high beam rigidity requires long focusing triplet that cannot be installed inside the cavity. Beam envelopes, presented in Fig.5, shows that the focusing period is robust against beam losses.

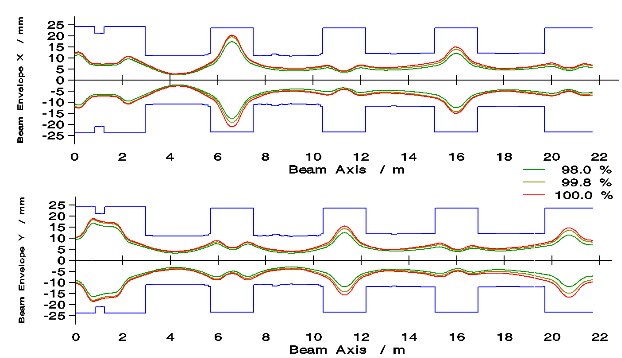

Figure 5: The transversal beam envelopes of the prestripper section.

The proposed prestripper linac has a length of $\approx$ 22 meters from the exit of HSI to the gas stripper and the relative RMS emittance growth is rather limited, around 16 % in all planes as shown in Fig.6.

CAVITY DESIGN

IH cavities represents the state of the art concerning ion acceleration in terms of RF efficiency in the low to medium β profile ($\beta \approx 0.01$ to 0.2). The new HE-linac consits of eight IH cavities, four IH in the prestripper section and other four in the poststripper section.

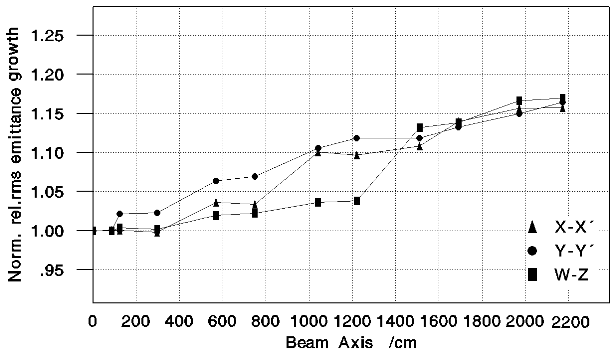

Figure 6: The relative RMS emittance growth up to the stripping position for a 20 mA U^{4+} beam.

Preliminary Microwave Studio simulations indicate that each prestripper cavity will have a length of about 3 meters, the total RF power, including the beam loading, will be less than 1.2 MW. This solution allows to use standard 108 MHz amplifiers and RF equipment.For example, Fig.7 shows a simulation model of the first IH cavity. Tab.1 summerizes the main parameter of the 8 cavities which define the 108 MHz section of the new HE-linac.

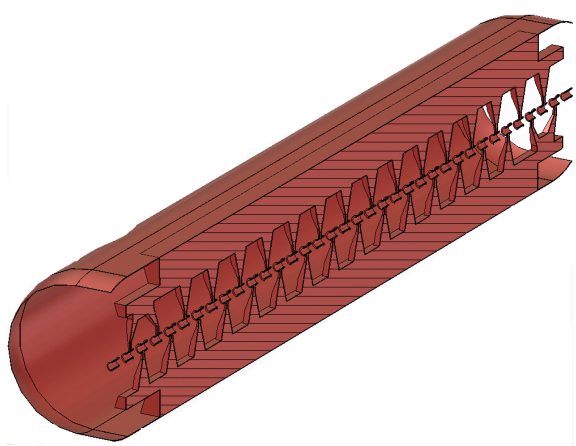

Figure 7: A simulation model of the first cavity of the HE-Linac.

Table 1: The main parameters of the 108 MHz IH cavities of the HE-Linac. (A=238)

Cavity (q)	ΔW (AMeV)	Eff. Volt (MV)	L (m)
IH 3 (+28)	0.400	25	2.9
IH 4 (+28)	0.450	26.7	3.1
IH 5 (+28)	0.416	26.8	3.1
IH6 (+28)	0.396	23.9	3.0
IH 7 (+38)	1.800	11.5	1.8
IH 8 (+38)	2.370	15.9	3.0
IH 9 (+38)	2.200	15.3	3.3
IH10 (+38)	2.200	15	3.7

LONG TERM OPTION

As final step of the new HE-Linac, a massive upgrade of the energy is under investigation. This option, which is ment to be realized after the construction of FAIR, foresees the direct injection into the FAIR SIS100 synchrotron. At the moment, a 100 AMeV linac based on 324 MHz CH-DTL seems a valid solution. Preliminary calculations in terms of beam dynamics are in progress, while, considering the cavity development, the design would significatly profit from the R&D work performed for the FAIR proton linac [7, 8].

CONCLUSION

The existing UNILAC will be more than 40 years old when the FAIR project will be commissioned at GSI. A new High Energy Linac (HE-LINAC) is under investigation at GSI in order to replace the existing Alvarez DTL section. That new linac is based on acceleration of U^{38+}, and foresees an output energy of 22 AMeV. The linac is entirely based on H-mode cavities. In a first step eight IH cavities at 108 MHz will accelerate 24 mA of U^{38+} to 11.4 AMeV and, a further acceleration is performed with CH cavities at 324 MHz. At the moment this option foresees an injection energy into the synchrotron at 22 AMeV. At that energy the space charge effect of the higher charge state will be then fully compensated. The higher injection energy will result in lower injection emittances as well.

Finally, as long term option, the new HE-Linac could be extended up to 100 AMeV in order to perform a direct injection into the FAIR SIS100 synchrotron. R&D activities on this final upgraded have been recently started.

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