FUTURE HEAVY ION LINACS AT GSI

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Abstract

An UNILAC-upgrade program will be realized in the next three years, providing for the high beam currents as required from the FAIR project (U^{28+}-beam intensity of 15 emA for SIS 18 injection). The replacement of the Alvarez-DTL by a new high energy linac is advised to provide a stable operation for the next decades. A linac upgrade option sufficient to boost the beam energy up to 150 MeV/u may help to reach the desired heavy ion intensities in the SIS 100. The SHE-upgrade program has also to be realized until 2011, such that an enhanced primary beam intensity at the target is available. It is planned to build a new cw-heavy ion-linac behind the present high charge state injector. This linac should feed the GSI flagship experiments SHIP and TASCA, as well as material research, biophysics and plasma physics experiments in the MeV/u-area. The whole injector family is housed by the existing constructions. Different layout scenarios of a multipurpose high intensity heavy ion facility will be presented.

INTRODUCTION

Besides two ion source terminals and a low energy beam transport system (LEBT) the High Current Injector

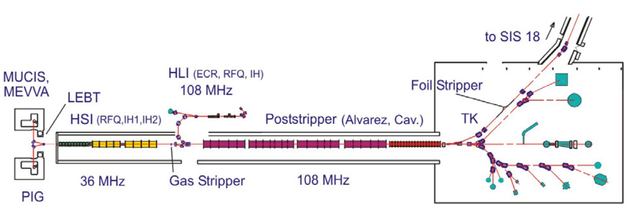

Figure 1: Schematic overview of the GSI UNILAC and experimental area.

(HSI) [1] of the UNILAC comprises a 36 MHz IH-RFQ (2.2 keV/u up to 120 keV/u) and an IH-DTL, consisting of two separate tanks, accelerating the beam up to the final HSI-energy of 1.4 MeV/u. After stripping and charge state separation the Alvarez DTL provides for beam acceleration up to $\beta = 0.155$. In the transfer line (TK) to the synchrotron SIS 18 a foil stripper and another charge state separator system can be used.

Highly charged ion beams from an ECR ion source of CAPRICE-type are accelerated in the High Charge State Injector (HLI) comprising an RFQ and an IH-resonator to 1.4 MeV/u. The HLI- as well as the HSI-injector serves in a time-sharing mode for the main drift tube linac. The ion beam delivered by the UNILAC may either be injected into the SIS 18 via TK or delivered to the experimental hall.

FAIR-UNILAC-UPGRADE

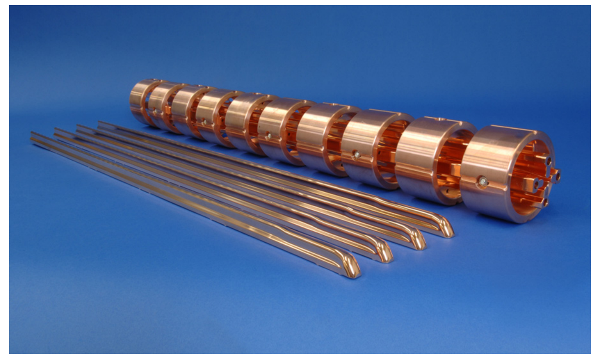

Figure 2: Redesigned and full copper plated HSI-RFQ-electrodes of tank 1; pre-assembled electrode cage.

Since the commissioning of the original HSI in 1999, several upgrade steps were performed. The super lens got new copper plated electrodes with reduced maximum surface field strength (2002), redesign and substitution of an inner triplet of IH1 (2003), mounting of copper plated RFQ-electrodes with an improved design of the input radial matcher (2004), resulting in an increased beam transmission, and a reduction of dark current contributions. The stripping efficiency for U^{28+} was improved by increasing the gas stripper density (2006). Finally, a maximum U^{28+}-current at the end of the transfer channel of 5.75 emA (2.7 emA of U^{73+}) was reached (2007). A new compact charge state separator in the transfer line (2008) allows improved matching to the SIS18. To provide the high beam currents as required from the FAIR project, the GSI-HSI must deliver 18 mA of U^{4+} ions. With the design existing up to 2008, the RFQ could not reach the beam currents at the RFQ output. As a first upgrade step, the RFQ has been modernized successfully in summer 2009 with a new electrode design. Furthermore the existing LEBT must be modified, and a new straight source branch, comprising a new U^{4+}-ion source terminal and a compact LEBT (2011-2013), will provide for the full beam performance. Re-commissioning of the HSI has shown that the transmission of the RFQ increased significantly (from 55% to 85% for high current uranium operation) [1]. Further upgrades aim to improve the HSI-transmission by optimizing the matching to the RFQ, and to the IH-DTL.

FAIR PROTON LINAC

The FAIR proton linac has to provide the primary proton beam for the production of antiprotons. It will deliver a 70 MeV beam to the SIS18 with a repetition rate of 4 Hz. The room temperature linac will be located north of the existing UNILAC complex. The main beam parameters are listed in Tab. 1.

Table 1: Main parameters of the proton linac for FAIR [2]

Final energy	70 MeV
Pulse current	70 mA
Protons per pulse	$7 \cdot 10^{12}$
Repetition rate	4 Hz
Transv. beam emittance	4.2 µm (tot. norm.)
Rf-frequency	325.224 MHz

The layout of the DTL has been revised. The use of rf-coupled CH-cavities (CCH) at energies beyond 35 MeV proofed to be not advantageous any more. The available power from the klystrons can be fully used also by a single CH cavity. Single cavities are easier w.r.t. the mechanical layout. CCH will be used just up to the extended diagnostic section (see Fig. 3).

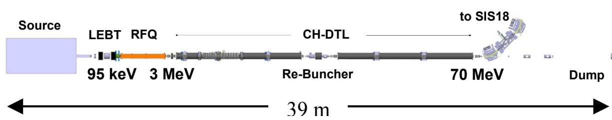

Figure 3: Layout of the FAIR-proton LINAC.

HEAVY ION HIGH ENERGY LINAC

Due to the increased number of failures and problems during operation particularly with the drift tubes, quadrupole magnets inside and the rf-tanks itself, the necessary high reliability of the Alvarez as the future FAIR-injector is not sufficiently guaranteed. This also applies to the corresponding high power rf- systems, supplying the Alvarez-structure. The high cross section for charge exchange processes of U^{28+} in the SIS18 generates significant beam losses and a significant increase in vacuum pressure during operation of the synchrotron. For this the use of a higher uranium charge state for injection into the SIS18 was investigated. In a comprehensive concept the replacement for the existing Alvarez linac, as well as a gradual expansion of the UNILAC is proposed:

- Complete replacement of the Alvaerez-linac by a 108 MHz-prestripper linac comprising four IH-tanks, increasing the post-stripper-charge state (U^{38+}) by shifting the current stripper section to a higher beam energy (3.0 MeV/u) (Fig. 4). The further acceleration to the final UNILAC beam energy is accomplished by using four additional 108 MHz IH-structures (stage 1).
- 325 MHz CH-linac within the existing tunnel to boost the UNILAC-beam energy up to 22 MeV/u (stage 2).

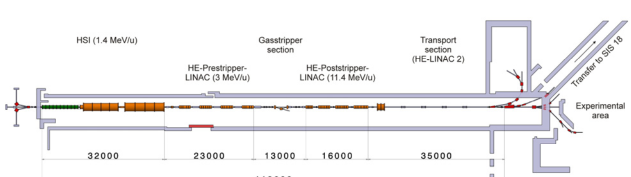

Figure 4: The proposed HE-LINAC (stage 1).

Essentially this concept is based on the high efficient interdigital H-field (IH)-, as well as the cross-bar H-field (CH)-structure, developed at the Institute of Applied Physics (IAP) and GSI. These structures allow for pulsed operation at significantly higher accelerating gradients. Besides the modernization of the more than 35-year-old RF amplifiers including the replacement of the 10 kW driver amplifiers and the 2 MW high power amplifiers is foreseen, as well as the use of programmable logic controllers, modernized electronics and data acquisition. Avoiding an increased space charge tune shift in SIS18 due to the higher charge state, the linac end energy have to be doubled to 22 MeV/u (stage 2). The increased beam energy reduces the linac emittance, while the SIS-injection efficiency is improved. The loss rate of U^{38+} ions due to dynamic vacuum effects is significantly lower than for charge state 28+. The proposed HE-linac is optimized as a FAIR injector designed with short beam pulses, low pulse-repetition rate and fixed linac end energy.

Table 2: Design-Parameter High Energy-Linac 1 (^{238}U) [3]

	HE-LINAC 1		HE-LINAC 2
Operation frequency	108.408 MHz		325.224 MHz
Length of linac	53 m		29 m
Total acc. voltage	148 MV		67 MV
	Prestripper	**Poststripper**	
Design charge state	4+	38+	38+
Beam energy (inj.)	1.4 MeV/u	3.0 MeV/u	11.4 MeV/u
Beam energy (final)	3.0 MeV/u	11.4 MeV/u	22.0 MeV/u
Magn. rigidity	14.90 Tm	3.10 Tm	4.25 Tm
Max. mass/charge	59.5	6.26	6.26
Design current	20 emA	24 emA	24 emA
Total acc. voltage	95 MV	53 MV	67 MV
No. of rf-cavities	4 IH, 1 reb.	4 IH, 1 reb.	6 CH.
No. of 1.6 MW rf-ampl.	5	5	(6 klystrons)

HEAVY ION CW-LINAC

In future the well established combination of High Charge State Injector (HLI) and main DTL is not dedicated as a high duty factor accelerator. While the UNILAC is designated as an injector for FAIR the beam time availability for SHE-research will be decreased due to the limitation of the future UNILAC for a low repetition rate (at a maximum rf-level). To keep the SHE program at GSI running, an upgrade program of the HLI was initialized comprising a new 28 GHz ECR source and a new cw capable RFQ. As a result of a long term cost-benefit analysis a standalone sc cw-linac in combination with the upgraded HLI is assumed to fit the SHE requirements at best. The technical design and the realisation of such a sc cw-linac in parallel to the existing UNILAC at GSI is assigned to a collaboration of GSI, Helmholtz-Institute Mainz (HIM) and IAP. A conceptual layout of a sc cw-LINAC [4] was worked out, which allows the acceleration of highly charged ions with a mass to charge ratio of 6 at 1.4 MeV/u from the upgraded HLI. Nine superconducting CH-cavities operated at 217 MHz accelerate the ions to beam energies between 3.5 MeV/u and 7.5 MeV/u, while the energy spread should be kept smaller than ±3keV/u. As beam focusing elements seven superconducting solenoids are applied. The general parameters are listed in table 3. A prototype of the first section (CH-demonstrator) comprising a superconducting CH-cavity as the key acceleration component embedded by two sc solenoids, will be realized (Fig. 5). Rf-testing at IAP and a full performance beam test at the GSI-HLI will be performed in the next 2 years.

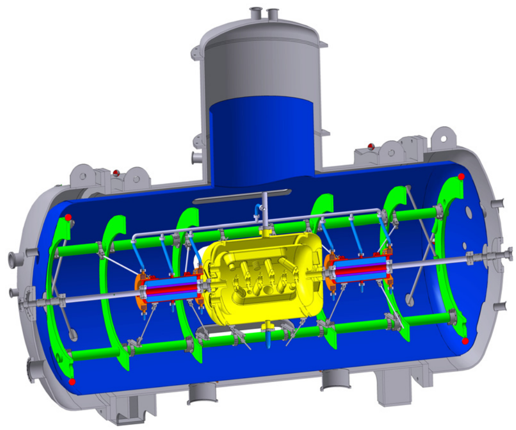

Figure 5: Scheme of the cw-LINAC Demonstrator; the CH-cavity (yellow) is embedded by two sc solenoids (red-orange). A reservoir of liquid helium as well as of liquid nitrogen is reserved (on the top) [5].

Table 3: Design parameters of the cw-LINAC [6]

Mass/Charge	
Operation frequency	216.816 MHz
Max. beam current	1 mA
Beam energy (inj.)	1.4 MeV/u
Beam energy (final)	3.5 - 7.5 MeV/u
Output energy spread	±3 keV/u
Length of acceleration	12.7 m
Sc CH-cavities	9
Accelerating gradient	5.1 MV/m
Sc solenoids	7

OUTLOOK

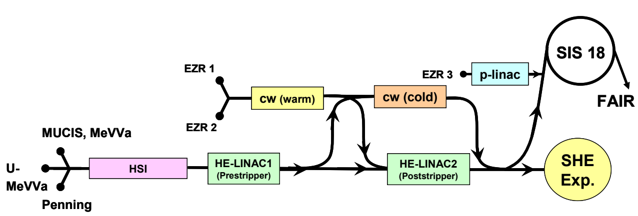

Figure 6: Complete GSI-injector environment.

The complete GSI-injector environment including the beam transfer lines is sketched in Fig. 6. The beam will be continuously transported between the cw-linear accelerator for highly charged ions (which will supply the heavy elements and materials research program) and the synchrotron injector (HE-linac). These beam lines are required in order to avoid restrictions on beam operation during construction times of the different linac systems. The warm cw-linac (HLI) in combination with the HE-linac (poststripper) will also serve as a synchrotron injector for rare isotopes delivered by the ECR-ion sources. Heavy ions, mainly uranium ions, from the HSI could be transferred to the cw-linac (cold), where a high duty factor ion beam will be accelerated for UNILAC experiments (e.g. for the material research cave). The high intensity proton beam from the p-linac will serve the synchrotron only.

Table 4: Time schedule for the GSI-injector linac upgrade

Year ⇒	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
UNILAC maintenance												
FAIR UNILAC upgrade												
SHE UNILAC upgrade I												
FAIR proton linac	Techn. design							Beam com-missioning				
cw CH-linac demonstrator												
sc-cw-linac	Techn. Design											
HE-linac (stage 1)		Techn. design										
HE-linac (stage 2)				Techn. design								

A maintenance program dedicated to the complete UNILAC will be performed in the next four years. During this time the HSI will be upgraded as a high intensity heavy ion FAIR-injector. The FAIR p-linac should be mounted until 2017. After completion of the technical design in the next three years, the HE-linac is gradually built up until 2019. Successful R&D at the cw-CH-linac demonstrator is a milestone for the complete sc-cw-linac, to be build until 2017. For the HE-linac 2 (energy booster) the R&D of new CH-cavities can be completed until 2016. The mounting of the CH-linac has to be performed in 2021, while FAIR could be operated with cw-linac and p-linac beams. Commissioning of the HE-linac 2 is foreseen for 2022.

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