LONG TERM PERSPECTIVE FOR THE UNILAC AS A HIGH CURRENT HEAVY ION INJECTOR FOR THE FAIR-ACCELERATOR COMPLEX

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Abstract

The present GSI-accelerator complex, consisting of the linear accelerator UNILAC and the heavy ion synchrotron SIS 18, is foreseen to serve as an U^{28+}-injector for up to 10^{12} particles/s for the future Facility for Antiproton and Ion Research (FAIR) at Darmstadt. In 2003 and 2004 different hardware measures and careful fine tuning in all sections of the UNILAC resulted in an increase of the beam intensity to $9.5\cdot10^{10}$ U^{27+}-ions per 100 µs or $1.5\cdot10^{10}$ U^{73+}-ions per 100 µs (max. pulse beam power of 0.5 MW). In addition a dedicated upgrade program for the UNILAC will be performed until 2009. It is intended to fill the SIS 18 up to the space charge limit of $2.7\cdot10^{11}$ U^{28+}-ions per cycle. The UNILAC serving as a high duty factor heavy ion linac for physics experiments is in operation since more than 30 years. After completion of the FAIR complex in 2015 the running time for the accelerator facility will be 20 years at least, while the UNILAC will then be in operation for more than 60 years. Different proposals for a new advanced short pulse, heavy ion, high intensity, high energy linac, substituting the UNILAC as a synchrotron injector, will be discussed. This new "High Energy-UNILAC" has to meet the advanced FAIR requirements, will allow for complete multi-ion-operation, and should provide for reliable beam operation in the future. We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395) and INTAS (project 03-54-3543).

INTRODUCTION

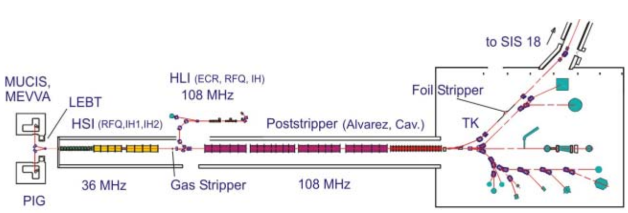

Fig. 1: Schematic overview of the GSI UNILAC and experimental area.

Besides two ion source terminals and a low energy beam transport system (LEBT) the High Current Injector (HSI) [1] of the UNILAC consists of a 36 MHz IH-RFQ accelerating the ion beam from 2.2 keV/u up to 120 keV/u and a short 11 cell adapter RFQ (Super Lens). The IH-DTL, consisting of two separate tanks, accelerates 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 without significant particle loss. The transfer line (TK) to the SIS 18 is equipped with a foil stripper and another charge state separator system.

Highly charged ion beams from an ECR ion source of CAPRICE-type are accelerated in the High Charge State Injector (HLI) consisting of an RFQ and an IH-resonator to final beam energy of 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 HLI may either be injected into the SIS via a transfer channel or delivered to an experimental hall.

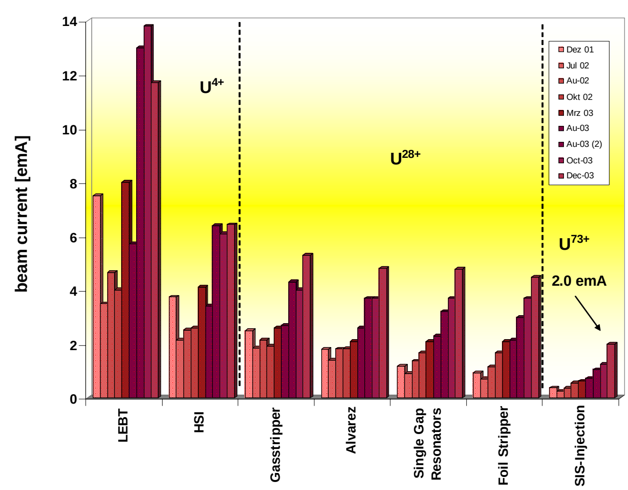

Fig. 2: Improvement of the UNILAC-Uranium beam intensities [2].

An extended experimental program dedicated to improve the overall UNILAC performance for heavy ion high current operation lead to an U^{73+} intensity of 2.0 emA (27.5 pµA) at the injection to SIS 18 [2]. This corresponds to $1.7\cdot10^{10}$ particles per 100 µs. Before foil stripping 4.5 emA (160 pµA) of U^{28+} beam intensity was achieved ($1.0\cdot10^{11}$ particles per 100 µs). The optimized total particle transmission through HSI, stripper section, Alvarez DTL, Single gap resonator chain, and TK is 50 %, if the particle losses during charge separation after the two strippers are taken into account. Compared to the design transmission (90 %) the lack is mainly caused by a bottle neck in the front-end area of the HSI-linac.

UPGRADE MEASURES

The improved ion source performance, an upgrade of the HSI-structures, the increased stripper gas density, the

Table 1: Future Requirements

purpose	upgrade measure	risk assessment	recommendation
FAIR-requirements: 15 emA, U^{28+} (0.5 TmA)	as described	Expected total operating time of the main DTL ≥ 50 years, high duty factor operation. After 30-40 years operating time: vacuum leak-ages at the 178 drift tubes	mid-term option (realized until 2010)
>15 emA, U^{28+}, (FAIR+)	not feasible with the existing UNILAC	-	-
Multibeam-Operation with ion beams of different rigidity	• fast ramped power supplies • 168 fastly ramped quadrupoles • 168 drift tubes	extremely high cost	no recommendation
Reduction of the "beam on target time" especially for the ambitious Super Heavy Element program - 50 % duty factor for A/q ≤ 5.9	• Exchange of the rf-power tube for Alvarez tank 1-3 (TH-526, 2 MW) • Operating with the 200 kW-rf-tube (RS1084CJ) – required average rf-power ≤ 46 kW	• Thermal stress for rf-contacts in the rf-circuits of amplifiers, cooling circuits/power tubes • Long-term operation of the rf power tubes RS2074HF with 330 kW (un-stable operation, reduction of opera-ting time) – significant influence for the UNILAC parallel operation as a FAIR-SIS-injector • The rf-power tube RS1084CJ/200 kW (for RFQ- und IH-cavity and single gap resonator operation) is not sufficient for 50 % duty factor (only 40 %). • high costs	no recommendation
see above, but100 % duty factor.	not feasible with the existing UNILAC	-	-

optimization of the Alvarez-matching, the reduction in the Single Gap Resonator section, the applied sweeper mode for foil stripper operation, and the use of various newly developed beam diagnostics devices comprised the successful development program. The UNILAC-upgrade for FAIR already started will be continued with the investigation of a new front-end for U^{4+} [3], stronger power supplies for the Alvarez quadrupoles, a charge state separator system in the foil stripper section, and versatile (partly non-destructive) beam diagnostics devices, sufficient for the operation with megawatt heavy ion beams. Additionally, the offered primary proton beam intensities will be increased by a new ambitious proton linac, which should be commissioned in 2012 [4].

The accelerator upgrade for the GSI heavy element program (SHIP-Upgrade) is based on a new high charge state injector front-end consisting of an advanced ECR ion source and an improved RFQ-accelerator. The largest step for the increase of the beam intensity is expected from a new a superconducting 28-GHz ECRIS source - this activity is supported through EURONS European Commission Contract No. 506065. The beam coming from the new ECR source will be delivered to the HLI by a second LEBT-system. A new RFQ for high duty factor-operation and an improved beam dynamics design is proposed. An upgrade program for all rf-amplifiers and rf-structures is foreseen to increase the duty factor from 27 % to 50 % for medium heavy projectiles like ^{70}Zn [5].

FUTURE REQUIREMENTS

For Uranium (reference ion) the UNILAC as an injector for FAIR has to deliver $3.3{\cdot}10^{11}$ U^{28+}-particles per 100 µs ($4{\cdot}10^{10}$ U^{73+}) to the present synchrotron SIS 18. With the FAIR-accelerator facility higher intensities will be achieved compared to the present GSI accelerators, through faster cycling and, for heavy ions, lower charge state which enters quadratically into the space charge limit (SCL). The desired energy of up to 1.5 GeV/u for radioactive beam production is delivered by the synchrotron SIS 100, which also generates intense beams of energetic protons up to 30 GeV for pbar-production. The energy of 30 GeV/u for heavy ions is generated by using higher charge states in combination with the slower cycling synchrotron SIS 300.

The different future requirements to the UNILAC-operation concerning FAIR and all the other experiments using high duty factor heavy ion beams with UNILAC-beam energy are summarized in Table 1.

LONG TERM PERSPECTIVE AS AN INJECTOR FOR FAIR

In a first step the replacement of the existing Alvarez-DTL is proposed, leading to a sustain FAIR-injector-operation for the next decades. A first conceptual layout is shown in Fig. 3: Behind the HSI a new 4 MV/m-IH-LINAC (108 MHz, length: 50 m) provides a high intensity 5 MeV/u U^{4+}-beam. The existing gas stripper section is reused to prepare for a beam intensity of 24 emA in charge state 42+. In the current LINAC-tunnel a high efficient 324 MHz-CH-LINAC (35 m) is able to boost the beam energy up to 30 MeV/u. In the transfer line to the SIS 18 a foil stripper and a new compact charge state separator system will be able to provide higher charge states (82+). If the gas stripper is replaced by a solid state stripper a LINAC-beam energy of 42 MeV/u (charge state 63+) will be realized. A further upgrade option may provide a second 100 m-CH-LINAC (324 MHz) to enhance the beam energy to up to 100 MeV/u (U^{41+})/150 MeV/u (U^{63+}), sufficient to feed the new 100 Tm-synchrotron (SIS 100) in direct line. The different LINAC-options are compared in Fig. 3 and Table 2 [6,7].

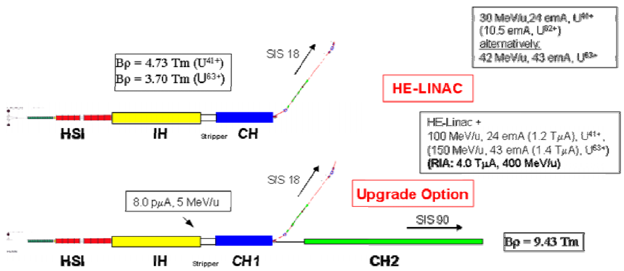

Fig. 3: Long-term LINAC-option for high intensity heavy ion beams for the FAIR accelerator facility.

Table 2: Comparison of Long-Term LINAC Options

	measure	output	purpose	comment
existing UNILAC	UNILAC + Upgrade + fast ramped quadrupoles 120 m tot. length	11.4 MeV/u, 15 emA, U^{28+} (5emA, U^{73+})	15 emA, U^{28+}, full multi beam operation	see risk assessment (tab. 1)
High Energy-LINAC (HE)	HSI (U^{4+}), additional 108 MHz_IH_ DTL (5 MeV/u), gasstripper section (24 emA, U^{41+}), 324 MHz-CH-DTL (4 MV/m) 125 m tot. length	30.0 MeV/u, 24 emA, U^{41+} (0.6 pmA) (10.5 emA, U^{82+}) alternatively: solid state-stripper: 42 MeV/u, 43 emA, U^{63+}, (0.7 pmA)	4.6×10^{11} ions/s achievable; reduced desorption rate; 50 % lower sc-tune shift → primary UNILAC-intensities may beincreased by a factor of 2	to be installed in the existing LINAC-tunnel, application of 2.5 MW-p-Linac-rf-klystrons
Upgrade option	HE_Linac + 324 MHz- CH-DTL II 225 m tot. length	100.0 MeV/u, 24 emA, U^{41+} (SIS_100) alternatively: 150.0 MeV/u 43 emA, U^{63+} (SIS_100)	direct injection into the SIS 100	Upgrade-option I for HE-Linac; application of 2.5 MW-p-Linac-rf-klystrons

A NEW CW-HEAVY ION-LINAC

Two different design versions represent stand alone linear accelerators, both with a 100 % duty factor. In the first version the maximum energy is 6 MeV/u achieved by normal conducting IH structures following the existing 1.4 MeV/u HLI-injector. Alternatively, a second version uses a sc-linac behind the normal conducting injector. Both LINAC-designs are described in [5, 8, 9].

OUTLOOK

- The UNILAC-upgrade program for FAIR will be realized; the required U^{28+}-beam intensity of 15 emA (for SIS 18 injection) should be available until 2010 [10].
- The replacement of the Alvarez-DTL by a new high energy linac is advised to provide a stable operation for the next decades.
- An additional 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 SHIP-upgrade program has also to be realized until 2010, such that an enhanced primary beam intensity at the target is available
- It is recommended to build a new cw-heavy ion-LINAC until 2012.
- A first conceptual layout of a multipurpose high intensity heavy ion facility concerning all the future requirements is shown in Fig. 4. The whole injector family is housed by the existing constructions.

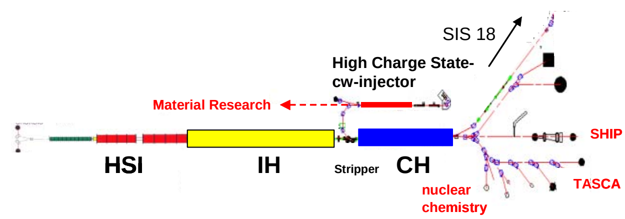

Fig. 4: Conceptual layout of a multipurpose high intensity heavy ion facility.

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