THE GSI-UNILAC - A MEGAWATT BEAM INJECTOR FOR FAIR

W. Barth, L. Dahl, L. Groening, S. Yaramyshev
Gesellschaft fuer Schwerionenforschung (GSI), Darmstadt, Germany
E-mail: S.Yaramishev@gsi.de

For the FAIR project the present GSI accelerator complex, consisting of the heavy ion high current linac UNILAC and the synchrotron SIS 18, is foreseen to serve as an injector for up to 10^{12} U^{28+}particles/s. Different hardware measures and careful fine tuning in all sections of the UNILAC resulted in an increase of the beam intensity to 10^{11} U^{28+} -ions or 2×10^{10} U^{73+} -ions per 100 μs. Further upgrade measures are described.

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1. INTRODUCTION

The present GSI-accelerator complex consists of the UNIversal Linear ACcelerator UNILAC (Fig.1) and the synchrotron SIS 18.

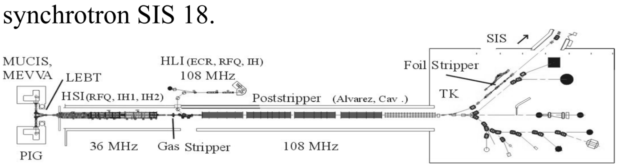

Fig.1. Schematic overview of the GSI UNILAC

It is foreseen to serve for the future synchrotron SIS 100 as an injector for up to 10^{12} U^{28+} particles/sec. For the international Facility for Antiprotons and Ion Research (FAIR) at Darmstadt (Fig.2) the present particle number in the SIS 18 has to be increased by more than two orders of magnitude.

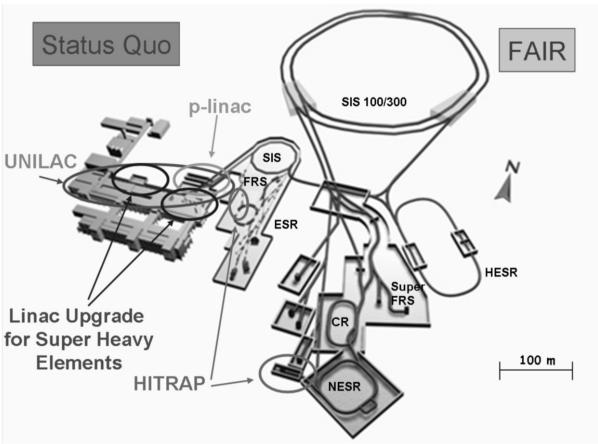

Fig.2. The accelerator facility FAIR at Darmstadt

The desired U^{28+}-energy of up to 2 GeV/u for radioactive beam production should be delivered by the synchrotron SIS 100, which also accelerates intense proton beams of up to 30 GeV for pbar-production. The maximum energy of 30 GeV/u for heavy ions is generated by using higher charge states in combination with the slower cycling synchrotron SIS 300. It can also be used as a stretcher for radioactive beams, which can be injected, cooled and stored in a system of rings with internal targets and in-ring experimentation. The various rings are optionally shared for the use with different beams [1].

2. THE GSI-UNILAC

The High Current Injector (HSI) of the UNILAC consists of ion sources (MEVVA-, MUCIS- or Penning-type); a low energy beam transport system (LEBT); the 36 MHz IH-RFQ accelerating the ion beam from 2.2 keV/u to 120 keV/u; the matching to the following IH-DTL with a short 11 cell adapter RFQ (Super Lens); the IH-DTL consisting of two separate tanks accelerating the beam up to the full HSI-energy of 1.4 MeV/u. Before injection into the Alvarez accelerator the HSI-beam is stripped and one charge state is selected (e.g. 28+ for uranium beams). The Alvarez accelerates the high intensity HSI beam without any significant particle loss. In the transfer line to the SIS 18 at 11.4 MeV/u a foil stripper and another charge state separator system is in use. For the longitudinal matching to the SIS 18, the single gap resonators can partly be used, as well as a dedicated 36 MHz-rebuncher in the transfer line [2]. The beam parameters for the uranium (as a design ion) are summarized in Table 1.

Table 1. *Design uranium beam parameters at UNILAC and SIS 18 injection*

	HSI entrance	HSI exit	SIS 18 injection	SIS 18 injection	Required for FAIR
Ion species	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{73+}$	$^{238}U^{28+}$
Current, emA	16.5	15	12.5	4.6	15.0
Part. per 100 μs	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$4.2\cdot10^{10}$	$3.3\cdot10^{11}$
Energy, MeV/u	0.0022	1.4	11.4	11.4	11.4
ΔW/W	-	$4\cdot10^{-3}$	$\pm1\cdot10^{-2}$	$\pm2\cdot10^{-3}$	$\pm2\cdot10^{-3}$
$\varepsilon_{n,x}$ / $\varepsilon_{n,y}$, mm mrad	0.3/0.3	0.5/0.5	0.75/0.75	0.8/2.5	0.8 / 2.5

Since 1999, when the HSI had been commissioned, many different ion species were accelerated in routine operation. The measured U^{73+} beam current at the SIS 18 entrance was increased from 0.3 emA in 2001 up to 2.0 emA in 2003. Newertheless for the recent design up to 4.6 emA should be delivered; requirements of the FAIR are even higher (15 emA).

3. UNILAC UPGRADE MEASURES

3.1. HIGH CURRENT INJECTOR

For the UNILAC operation with intense uranium beams the MEVVA-ion source was renewed and significantly improved [3]. An U^{4+} fraction of up to 67% was reached.

Due to the high rf surface field in the RFQ and in the Super Lens, rf-conditioning was done in a time sharing mode. In 2002 the Super Lens was completely dismounted and new electrodes were fabricated. The rf-performance was significantly improved: the field strength was slightly decreased, the surface quality was improved, and a new plunger design was applied [4].

In 2004 a comparable upgrade measure for the RFQ was performed. The operation of the HSI-RFQ required significantly higher input rf-power. For the new RFQ electrodes additional copper plating leads to a reduction of "dark currents" during high power operation. A dedicated procedure for the control of the copper-plating was realized [5].

The Input Radial Matcher (IRM) at the entrance of the RFQ (about 1% of the RFQ length) was redesigned to improve the transmission through the whole front-end system. After recommissioning of the RFQ, the results of the calculations with the DYNAMION code [6] were confirmed by the measurements with a high current argon beam (16 emA). A high current uranium beam was not available at that time. For a low current U^{4+} beam (< 0.5 emA) the 100% transmission was reached first time.

After a breakdown of the IH-1 tank an internal triplet lens housed in a large drift tube was substituted to obtain better rf performance of the resonator. Stable operation of the tank was achieved. A special machine investigation program was performed to optimize the rf parameters of IH-1 and IH-2. The rf -phase and the -voltage in each tank were optimized to provide for low longitudinal emittance, being required for the separation of the U^{28+} ions after stripping process, as well for beam matching to the following Alvarez structure.

3.2. GASSTRIPPER PERFORMANCE

With the reduction of the available apertures in the stripper box, it was possible to increase the stripper gas density by 50%. For medium intense uranium beams (6.5 emA, U^{4+}) this leads to the expected gain for the desired charge state 28+ (up to 12.8%). The desired equilibrium charge state distribution is reached for a 70 % higher gas density. Currently the power of the vacuum pumps is not sufficient to compensate this gas load. For temporary 70%-increase of the gas density the measured total uranium current (all species) was increased to 41 emA. The defocusing effect of the space charge forces leads to particle loss in the transport section after the stripping area. This can be compensated by increasing the transverse beam spot in the space charge dominated beam transport. For the proposed higher uranium intensities the present stripper section is not sufficient to meet the FAIR-requirements and has to be redesigned.

3.3. ALVAREZ SECTION

Usually, the empirical matching can be done by the quadrupoles, preceding the DTL, until a transmission through the Alvarez section of more than 90% is achieved. In order to increase the transmission close to 100%, a systematic matching procedure was proposed and realized during machine experiments. Beam Twiss-parameters, obtained from the emittance measurements in between quadrupoles, are transformed back to the beginning of the matching channel. To match the beam to the periodic solution for the 1st Alvarez tank, a fitting routine involving the five quadrupoles is applied. For the highest available uranium intensity the losses along the Alvarez were reduced from 8% to less than 1% [7].

The postaccelerator performance can also be improved by optimization of the quadrupole settings in the DTLs, being most important in the 1st Alvarez tank. Due to the high mass over charge ratio (m/ζ) of $^{238}U^{28+}$ ions, the maximum zero current phase advance σ_0 in the Alvarez DTL is limited to 45°, mainly by limitations of the quadrupole power supplies. For a $^{40}Ar^{10+}$ beam the m/ζ is lower; so that the phase advance influence on the transmission in the Alvarez DTL can be investigated in the interesting range of σ_0-values. As shown in Fig.3, a phase advance $\sigma_0 \geq 50°$ is required for an improved beam brilliance.

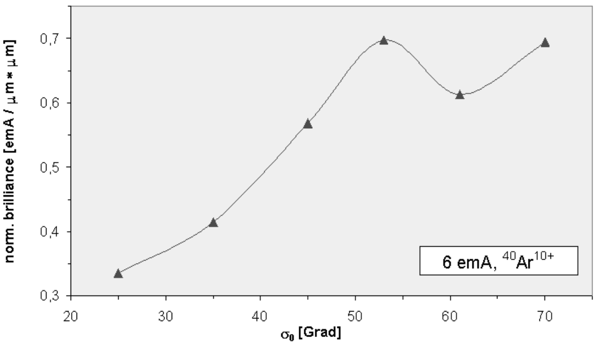

Fig.3. Measured normalized beam brilliance for a high current argon beam after the 4th Alvarez-tank as a function of phase advance σ_0

3.4. UNILAC TRANSMISSION

As shown in Fig. 4, the uranium beam intensities along the UNILAC and transfer line were increased during 2002 and 2003. Mainly the increased primary beam intensity from the MEVVA ion source, the higher beam stability and availability allowed for machine tuning with space charge dominated uranium beams. In 2003 a maximum U^{73+}-intensity of $1.7 \cdot 10^{10}$ particles per 100 µs (10^{11} particles per 100 µs, U^{28+}) was obtained. Nevertheless the reached beam quality is still below the requirements of FAIR due to the high horizontal beam emittance. Further measures are foreseen to increase the beam brilliance at the SIS 18 entrance.

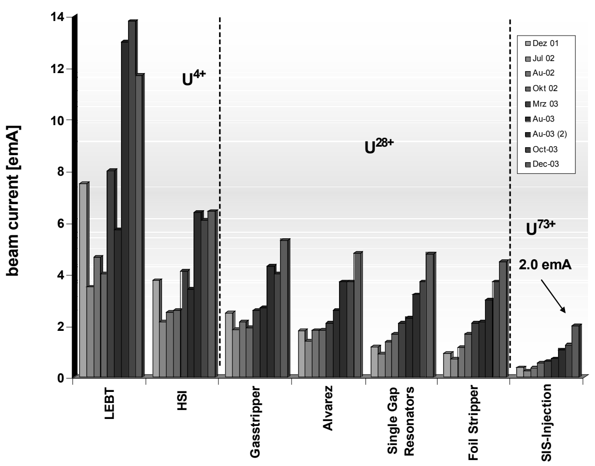

Fig.4. Improvement of the UNILAC uranium beam intensities during the last years

4. FURTHER UPGRADE PROGRAM

It is planned to investigate the beam forming process (after the ion source) during post-acceleration with a dedicated test bench. Presently the main bottle neck regarding transmission loss under space charge conditions is the HSI-front end system, which does not fit to the delivered beam quality in the LEBT. An extended investigation program should result in a proposal for a new high current uranium front end system. The space charge dominated beam matching to the poststripper DTL as well as the beam brilliance in the transfer line has to be improved. It is planned to substitute part of the power supplies of the Alvarez-quadrupoles resulting in a higher phase advance and less emittance growth in the DTL. For charge state separation of high intensity heavy ion beams at 11.4 MeV/u a compact charge state separator is foreseen. This device had already been designed and is ready for order. An upgrade program for additional non- destructive beam diagnostics, sufficient for high current operation, is still in progress.

The antiproton physics program of FAIR is based on a rate of $7 \cdot 10^{10}$ cooled antiprotons per hour. The offered recently primary proton beam intensities will be increased by a dedicated proton linac [8].

The present GSI accelerator facility delivers highly-charged ions up to U^{92+} at an energy of 400 MeV/u. The high quality beams are provided by means of stochastic and electron cooling and decelerated down to 4 MeV/u. The further deceleration down to 6 keV/u for the HITRAP is another linac project, ready for operation in 2008 [9].

For the advanced experimental program for the production of super heavy elements (SHIP) efforts to improve the average target luminosity for medium heavy ions in the MeV/u-range is foreseen.

5. CONCLUSION AND OUTLOOK

During the last years an uranium beam intensity, delivered from the UNILAC to the SIS 18, was increased by a factor of seven. Nevertheless for the FAIR project another factor of five is required as well as an improved beam quality. It needs a serious upgrade of the present UNILAC as high current heavy ion injector for the whole facility. Several upgrade programs are already under investigation including international collaborations with ITEP (Russia) and KIPT (Ukraine). Additionally, several linac projects are under consideration at GSI, namely a dedicated high current proton linac, a decelerator of highly-charged ions (HITRAP) and a CW linac for the production of super heavy elements.

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GSI-UNILAC – МЕГАВАТТНЫЙ ИНЖЕКТОР ПУЧКА ДЛЯ FAIR

W. Barth, L. Dahl, L. Groening, С. Ярамышев

Представлен GSI усилительный комплекс, состоящий из сильноточного линейного ускорителя тяжелых ионов UNILAC и синхротрона SIS 18, который предназначен для работы в качестве инжектора до 10^{12} U^{28+}частиц/с проекта FAIR. Различные измерения аппаратуры и тщательная тонкая настройка всех секций UNILAC привели к увеличению интенсивности пучка до 10^{11} U^{28+} -ионов или $2{\times}10^{10}$ U^{73+} -ионов на 100 мкс. Описана его дальнейшая модернизация.

GSI-UNILAC – МЕГАВАТНИЙ ІНЖЕКТОР ПУЧКА ДЛЯ FAIR

W. Barth, L. Dahl, L. Groening, С. Ярамишев

Представлено GSI підсилювальний комплекс, що складається з потужнострумового лінійного прискорювача важких іонів UNILAC і синхротрона SIS 18, що призначений для роботи як інжектор до 10^{12} U^{28+}часток/с проекту FAIR. Різні виміри апаратури і ретельне тонке настроювання всіх секцій UNILAC привели до збільшення інтенсивності пучка до 10^{11} U^{28+} -іонів або $2{\times}10^{10}$ U^{73+} -іонів на 100 мкс. Описана його подальша модернізація.