ADVANCED UNILAC UPGRADE FOR FAIR

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Abstract

To provide for the high beam currents as required from the FAIR project, the GSI Unilac High Current Injector (HSI) must deliver 18 mA of U^{4+} ions at the end of the prestripper section. With the design existing up to 2008, the RFQ could not reach the necessary beam currents at the RFQ output, as shown by simulations. 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 will provide for the full beam performance.

Commissioning of the HSI has shown that the transmission of the RFQ increased significantly (from 55% to 85% for high current uranium operation, 95% for medium current operation). Further upgrades aim to improved HSI-transmission by optimizing the matching to the RFQ, and to the IH-DTL. The upgrade of the LEBT starts in 2010.

INTRODUCTION

The GSI Universal Linear Accelerator UNILAC comprises the High Current Injector HSI, the High Charge State Injector HLI and the poststripper section (Alvarez and Single Resonators). The HSI comprises two ion source terminals (2.2 keV/u), a low energy beam transport system LEBT, an RFQ (120 keV/u), a short adapter RFQ (Superlens) and an IH-DTL (two tanks, 1.4 MeV/u). The UNILAC serves for the synchrotron SIS18 by a transfer channel.

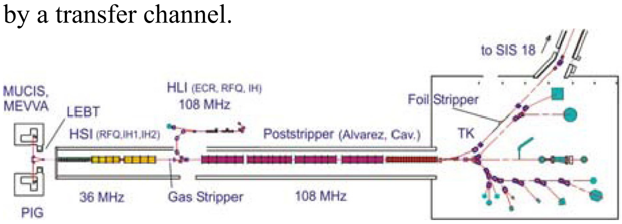

Figure 1: GSI UNILAC schematic overview.

HSI RFQ UPGRADE

Since the commissioning of the original HSI in 1999, several upgrade steps were performed: In 2002 the Superlens got new copper plated electrodes with reduced maximum surface field strength. After a breakdown in the IH1-tank 2003, the mantle of one drift tube was redesigned. In 2004 the RFQ got new copper plated electrodes with an improved design of the input radial matcher (IRM), resulting in an increase of high current beam transmission by 15 %, and reduction of dark current contributions. The stripping efficiency for U^{28+} was improved by increasing the gas stripper density (by 50 %). The maximum U^{73+}-current at the end of the transfer channel was increased to 2.7 emA in 2007 [1]. A new charge state separator in the transfer channel (Dec. 2007) allows better matching to the SIS18.

The RFQ never reached the design electrode voltage of 137 kV (mass/charge = 65), nor the designed transmission (90%). DYNAMION simulations with the original design showed that the existing RFQ does not meet the FAIR requirements (Figure 2) [2].

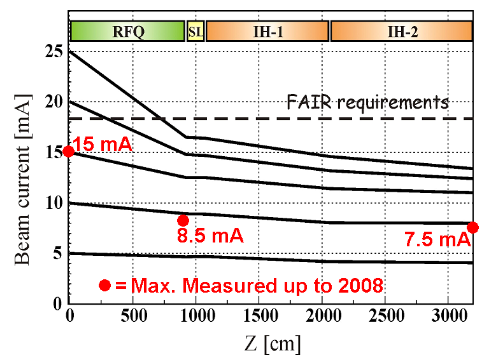

Figure 2: Uranium beam current for different input currents (simulations performed by the DYNAMION code).

Table 1: RFQ upgrade 2009 schedule

Electrodes and carrier rings fabrication, assembly	July 2008 - April 2009
RF tuning (prelim. assembled)	May 2009
Final assembly in beamline	June 2009
Beam-commissioning with $^{40}Ar^{1+}$	July 2009
Beam-commissioning with $^{238}U^{4+}$, routine heavy ion high current operation	≥ Sept. 2009

Simulations

During the upgrade in 2004 the high reliability of the advanced simulation code DYNAMION had been proved [3]. All machine conditions, geometries and settings were considered. DYNAMION predicted for the RFQ with the new designed IRM a transmission increase of 15 %, what was in good agreement with measurements.

For the upgrade 2009, new RFQ designs have been developed with the code DESRFQ. For the different RFQ designs, HSI end-to-end simulations have been performed with DYNAMION (RFQ) and LORASR (Superlens and IH). With enlarged aperture and higher voltage (155 kV instead of 125 kV at Uranium level, but lower surface peak field) the final design provides an increased acceptance. An additional cross-checking of the RFQ simulations with PARMTEQ-M was performed [4].

Investigations on the beam brilliance emphasized the usefulness of the new design, taking into account losses in the whole HSI: within an emittance of 20 µm (behind RFQ) the requirements for FAIR (18 mA) can be reached [5].

† Sergey Minaev deceased on March 11, 2010

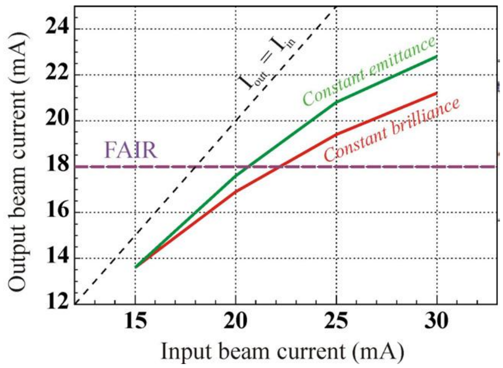

Figure 3: Simulated RFQ U^{4+} beam current.

Table 2: Design parameters of the HSI-RFQ

HSI-RFQ	New Design	Existing Design (up to 2008)
Electrode voltage / kV	155	125
Av. aperture radius / cm	0.6	0.54 – 0.52 – 0.77
Electrode width / cm	0.846	0.93 – 0.89 – 1.08
Maximum field / kV/cm	312.0	318.5
Modulation	1.012 – 1.93	1.00 – 2.09
Min. transv. phase advance / rad	0.555	0.45
Synch. Phase, degrees	-90^0 - -28^0	-90^0 - -34^0
Min. aperture radius, cm	0.410	0.381
Norm. transv. acceptance / µm	0.856	0.73
Number of cells with modulation	394	343
Length of electrodes, cm	921.74	921.74

For further use of the existing tank, the electrode length was kept unchanged. The longitudinally constant new transverse shape of the electrodes (constant capacitance) and the new length of carrier rings (all equal) were designed by simulations, based on measurements at the original resonator in 2004.

Mechanics, Copper plating, RF Conditioning

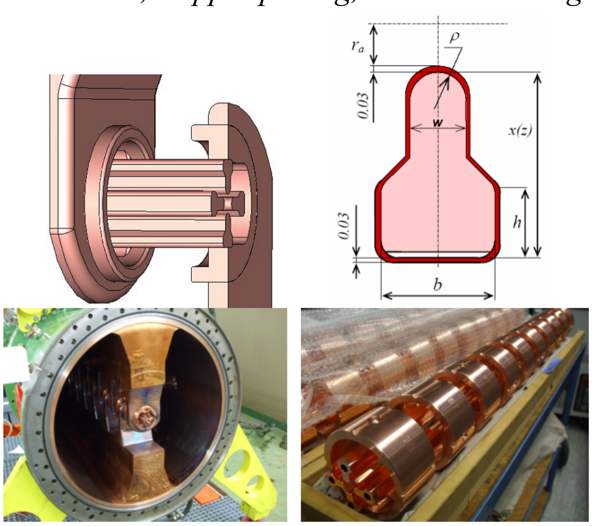

Figure 4: Upper row: HSI-RFQ electrode channel and geometry; lower row: RFQ tank opened during assembly works; pre-assembled electrode cage.

The new electrodes have been manufactured in the GSI workshop. The first sets of RFQ and Superlens electrodes (1999) showed surface damages from RF and beam operation, the new electrodes were copper plated, as in 2004. A 0.03 mm layer of electrolytic copper reduces dark current contributions. This measure is assumed to be most important for the application of very high voltages. After reassembly of the RFQ, RF tuning work confirmed the predicted properties. As expected from simulations, only six fixed plungers for fine tuning were needed.

With the upgraded RF power supply, conditioning took four days for argon level (104 kV, 330 kW), three more weeks for uranium level (155 kV, 1.2 MW; decreasing to 1.05 MW after twelve months of beam operation) (Figure 5).

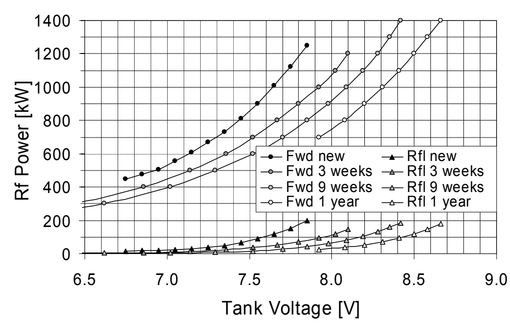

Figure 5: RF power levels (forward/reflected) reached after conditioning periods.

Beam commissioning

Beam commissioning with an Ar^{1+} high current beam started in July 2009 with an emittance meter installed behind the RFQ, resulting in a transmission gain of 50 %. After optimization in 2010 up to 85% of 12.5 mA input beam current were transported through the quadrupole quartet and accelerated through the new RFQ.

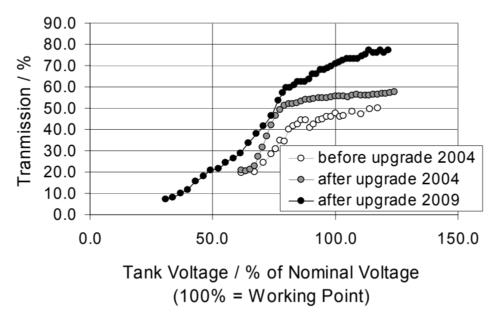

Figure 6: Measured Ar^{1+} high current transmission of the HSI-RFQ (Input 16 mA).

A two times larger RFQ output emittance compared to the initial RFQ-commissioning is a consequence of the increased acceptance and significantly higher transmission.

Table 3: Measured RFQ output emittance

Argon High Current (90% KV) Emittance behind RFQ		
Measured	*1999*	*2009*
ε_x	11.3	22.9
ε_y	12.6	20.7

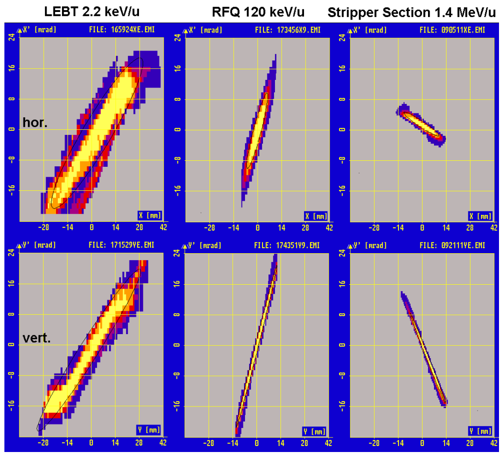

Figure 7: Measured Ar^{1+} high current HSI-emittance.

During re-commissioning of the complete HSI (incl. Superlens and IH) with Ar^{1+}, the designed RFQ beam energy of 120 keV/u was confirmed. The measured beam current of 8.5 mA Ar^{1+} behind the HSI (at 1.4 MeV/u, stripped 13 mA Ar^{10+}) is the highest ever reached argon beam current, exceeding the old HSI record of 8.0 mA, even despite a lower input current (13 mA instead of 16 mA).

Optimisations with a medium current U^{4+} beam in March 2010 gave maximum transmission values of 95% through the quadrupole quartet and the RFQ (input beam current 7 mA U^{4+}, LEBT settings optimized, Figure 8).

Due to a limited size of slits and grids, the beam emittance in the LEBT was not fully measured. Further optimisation is expected from the HSI-LEBT Upgrade.

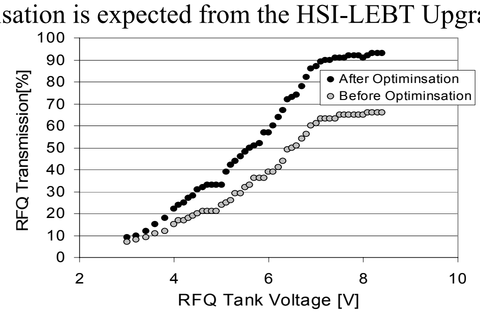

Figure 8: U^{4+} transmission (7 mA).

Table 4: HSI maximum high current transmission

	U^{4+}		Ar^{1+}	
Beam current/ Transmission	before upgrade	2010 (2009)	before upgrade	2009
Before QQ	12.4 mA	7 mA (11)	13.5 mA	12.5 mA
Behind RFQ	7.9 mA	6.6 mA (7.5)	7.6 mA	9.5 mA
Transm. RFQ	64 %	95 % (70%)	56 %	85 %
Behind HSI	6.6 mA	5.1 mA (6.0)	5.9 mA	8.5 mA
Transm. HSI	50 %	72 % (60%)	44 %	56 %

Table 5: Measured transverse emittance in the LEBT

	U^{4+}		Ar^{1+}	
	2004	2009	2004	2009
inp. beam curr. /mA	8.5 (15)	10	8	13
ε_x/mmmrad (90% ,4*rms)	140 (200)	130	110	190
ε_y/mmmrad (90% ,4*rms)	125 (200)	100	150	130
X/Y / mm	±20/28	±24/20	±20/28	±28/28
X'/Y' / mrad	±12/20	±12/25	±18/15	±16/20

FURTHER UPGRADE STEPS

High current requirements for the HSI cannot be fulfilled with the existing LEBT. In the LEBT upgrade the switching magnet, the emittance measurement device and the quadrupole quartet will be replaced, with wider apertures they will allow optimization of the beam matching to the RFQ. New beam diagnostics components (with bigger apertures) are already ordered.

For further improvements of the beam brilliance an additional straight-line ion source branch with two sc solenoids is planned (Compact LEBT, [6]). One solenoid of this type is already tested successfully at GSI.

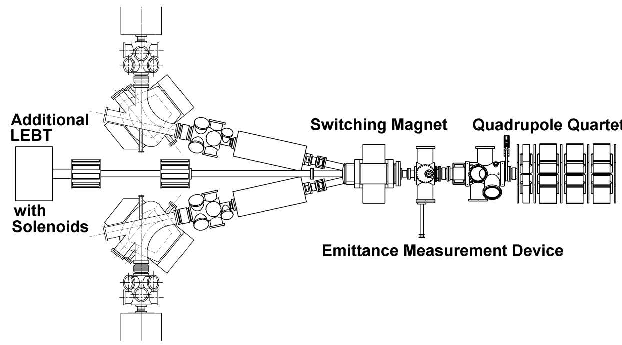

Figure 9: HSI Frontend upgrade scheme.

The power supplies for all Alvarez quadrupoles have been replaced in 2008/2009. An increased number of quadrupole families along the Alvarez section provides for more flexible focussing, higher magnet current limits allow for better achievable beam quality[7].

SUMMARY AND OUTLOOK

The HSI-RFQ Upgrade resulted in significant increase of high current transmission. In particular, 95 % RFQ transmission for a 7 mA U^{4+}-beam was reached, as well as a highest ever reached $^{40}Ar^{1+}$-beam of 8.5 mA behind the HSI. Future upgrade steps will provide for full performance as required for FAIR.

ACKNOWLEDGEMENTS

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