U^{28+}-INTENSITY RECORD APPLYING A H_2-GAS STRIPPER CELL

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Abstract

To Meet the FAIR science requirements higher beam intensity has to be achieved in the present GSI-accelerator complex. An advanced upgrade program for the UNILAC aimed to meet the FAIR requirements is ongoing. Stripping is a key technology for all heavy ion accelerators. For this an extensive research and development program was carried out to optimize for high brilliance heavy ion operation. After upgrade of the supersonic N_2-gas jet (2007), implementation of high current foil stripping (2010 and 2011) and preliminary investigation of H_2-gas jet operation (2012), a new H_2-gas cell using a pulsed gas regime synchronized with arrival of the beam pulse was recently developed. An obviously enhanced stripper gas density at a simultaneously reduced gas load result in an increased stripping efficiency, while the beam emittance remains the same. A new record intensity (7.8 emA) for U^{28+} beams at 1.4 MeV/u has been achieved applying the pulsed high density H_2 stripper target, exploiting a high intensity U^{4+} beam from the VARIS ion source with a newly developed extraction system. The experimental results will be presented in detail.

STRIPPING OF HEAVY ION BEAMS

Suitable charge stripper technologies [1] are crucial to meet the challenging demands of state of the art heavy ion accelerator facilities. At FAIR - presently under construction at GSI - the existing linear accelerator UNILAC and the synchrotron SIS18 will serve as injector chain for the FAIR SIS100 synchrotron. Different approaches are investigated to increase the stripping efficiency of the heavy ion beam at 1.4 MeV/u and to generate higher charge states [2–5]. The stripper target at 1.4 MeV/u has to cope with a very high ion beam power of up to 1.5 MW for 18 emA U^{4+} beams during short beam pulses (100 µs) at low duty cycle (2.7 Hz rep. rate). Though for high beam powers gas or liquid strippers have clear advantages compared to foil strippers concerning durability and operational reliability, gas strippers lead to much lower equilibrium charge states due to the strongly reduced influence of the density effect [6–8] compared to solid strippers. Since electron capture cross sections of the heavy ions especially in the low-Z gases are considerably suppressed [8, 9], in particular hydrogen promises higher equilibrium charge states as compared to e.g. nitrogen, which is routinely used at the UNILAC gas stripper [10].

Thus a new setup, suitable for H_2 operation has been constructed. To enhance the gas density a pulsed gas injection [11] was implemented. This allows an increase of the maximum gas pressure and creates a high-pressure interaction zone for the stripping process. The time between two pulses is used to remove most of the gaseous particles from the system before injection of the next pulse.

UNILAC STRIPPER SECTION

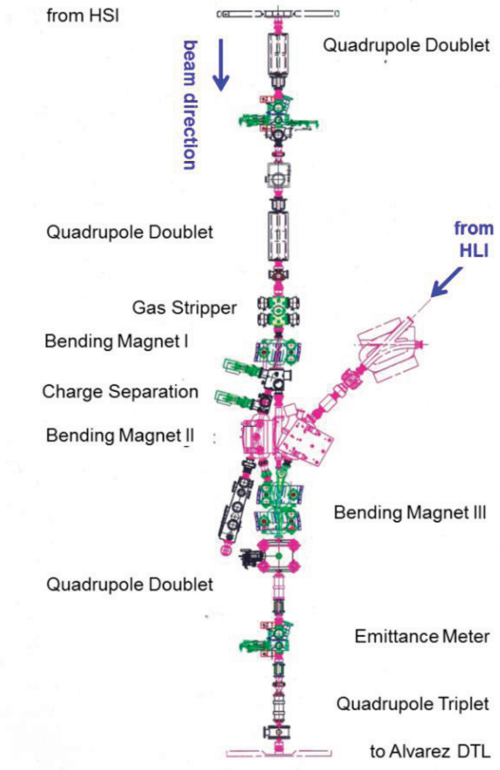

Figure 1: Layout of the 1.4 MeV/u stripper section; 14.0 m total length.

For the UNILAC a stripper section [12] was redesigned and installed in 1999 (Fig. 1). Charge separation and beam transport under highest space charge conditions and multi beam operation with pulsed magnets was established. A supersonic N_2-gas jet produced by a Laval nozzle crosses the ion beam in the central interaction region of the gas stripper chamber. Two sections of differential pumping upstream and downstream of the central region are pumped by four powerful turbo pumps (pumping speed 1200 l/s). The charge separator

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comprises three bending magnets, operating in pulsed mode, based on a 50 Hz repetition frequency. In the following transport line the transversal and longitudinal matching to the poststripper accelerator is accomplished.

BEAM EXPERIMENTS WITH A PULSED GAS STRIPPER CELL

Characterizing the stripping performance, the absolute stripping efficiency into the desired charge state is a key indicator. A sufficient charge state resolution is required to enable highest intensities in the desired charge state.

To compare the performance of the modified stripper setup with that of the existing gas-jet stripper, uranium beam measurements in both setups were conducted with a N_2-target. It could be shown in [11] with Bi-beam that the measured relative charge state spectrum for jet operation as well as for the pulsed gas cell is the same inside the error limits, if the equilibrium charge state is reached.

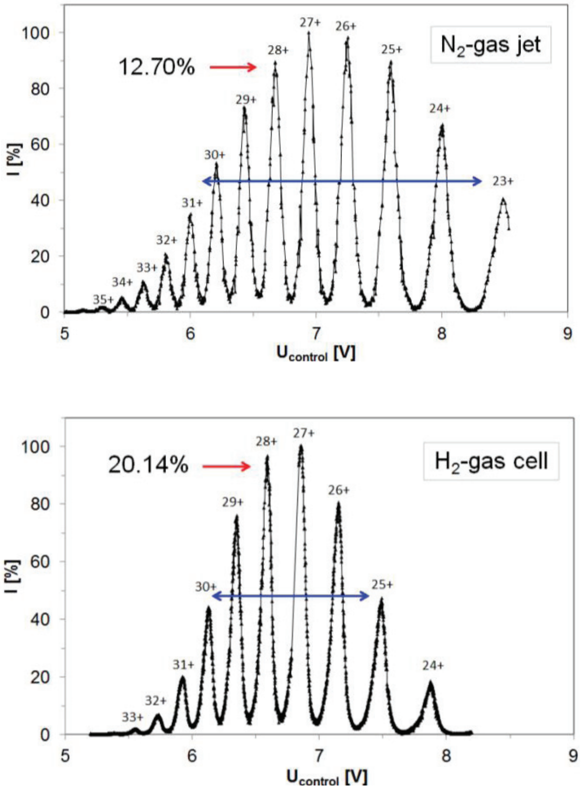

Figure 2: N_2-gas jet (top) and H_2-pulsed gas cell (bottom) charge spectra for max. available target density [13].

As shown in Fig. 2, the measured charge stripping distribution using the maximum target thickness available for N_2-jet operation shows a relatively broad distribution (FHWM ≈ 7 charge states), but well separated peaks. The same level of separation purity was observed for H_2-gas cell operation. But the width of distribution is much narrower (FHWM ≈ 4.5 charge states) and the shape of distribution is obviously more symmetric. As a result the relative maximum is significantly increased, while the peripheral areas are diminished. Besides, the maximum of the distribution is shifted by one charge state. The evaluation of charge spectra resulted in a 59% higher stripping efficiency for U^{28+} as the most interesting uranium charge state for FAIR injector operation. Assuming an increased stripping efficiency for thicker targets, high current uranium operation for post stripper acceleration with even higher charge states appears possible [13].

Table 1: Measured Beam Parameters [13]

	N_2-gas jet	H_2- pulsed gas
Stripper-(pre-)pressure	0.4 MPa	12.0 MPa
U^{4+}-current (HSI)	≈6.0 emA	
Max.U^{28+}-current	4.5 emA	7.8 emA
Total current (stripped)	24 emA	34 emA
Stripping efficiency	12.70%	20.14%
Energy loss	30 keV/u	22 keV/u
ε_x (90%, tot.) norm.	0.76 µm	0.70 µm
ε_y (90%, tot.) norm.	0.84 µm	0.93 µm
Hor. beam brilliance	5.32 mA/µm	10.03 mA/µm
FAIR requirement:		
ε_x (tot.) norm.	1 µm	
U^{28+}-Intensity	15 mA	
Hor. beam brilliance	15 mA/µm	

For further acceleration of the desired charge state (28+), it is important to characterize the beam quality before injection into the following accelerator section. The beam emittances have been determined by using a measurement system [14] based on a slit and SEM-grid system for horizontal and vertical plane separately. Despite expected higher space charge driven emittance growth for the H_2-gas cell operation, for both targets the average transversal beam emittance remains the same inside a measurement error area of ±2%, while the horizontal emittance for H_2-gas cell operation is 10% less. The target driven losses of beam energy has been measured by the time of flight method using pick up probes (with target switched on/off) in the matching section behind gas stripper and separation system with high resolution (±0.1%). The use of the N_2-target results in a beam energy loss of 20 keV/u, while for the operation with the thick H_2-target a loss of 12 keV/u was measured. Backward calculation of the target thickness resulted in 44.9 µg/cm^2 (LISE++ [15]) and 40.8 µg/cm^2 (SRIM [16]) for the N_2-target and 9.3 µg/cm^2 (LISE++) and 6.3 µg/cm^2 (SRIM) for the H_2-target. The high current uranium beam measurements are summarized in Table 1.

BREAKING THE URANIUM RECORD

The entire Injector system was optimized for high intensity operation. A newly developed multi aperture beam extraction system was installed. The VARIS ion source [17, 18], the extraction system, the post acceleration gap, the Low Energy Beam Transport (LEBT) system and the matching line to the RFQ were optimized using a 25% higher U^{4+} beam current extracted from the ion source., a beam current of 15.3 emA was available for further acceleration in the High Current Injector (HSI), as shown in Fig. 3. As a result the HSI could provide for stable and reliable high current uranium operation, necessary for advanced and careful matching of the high power U^{4+} beam to the gas stripper cell. Finally a U^{28+} beam current of 7.8 emA was obtained at 1.4 MeV/u.

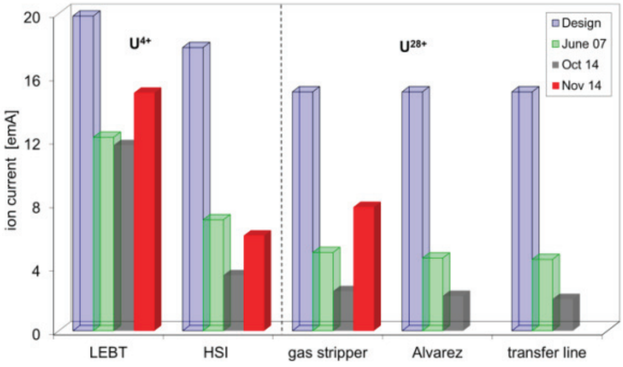

Figure 3: Achievement of a new uranium beam (28+) intensity record at GSI-UNILAC.

Figure 3 shows the FAIR-uranium beam intensity requirements along the UNILAC and transfer line to the SIS18. The latest peak record had been achieved in 2007 with 30% of the FAIR-U^{28+} beams current accomplished at the end of the transfer line. More recently, the available beam current at this position was 13% of the design value only, caused by strong HSI-performance degradation. Now more than a factor of three higher U^{28+} beam current is available at 1.4 MeV/u, exceeding the latest peak record by 56%.

OUTLOOK

More than 50% of U^{28+}- FAIR intensity requirements and 65% of U^{28+}- FAIR beam brilliance was accomplished recently. The stripper performance could be optimized applying significantly higher target densities. A higher primary beam intensity was available after installation of a new extraction system. Further optimization of stripper performance will be started in the framework of an advanced machine experiment program; applying thicker targets aims for post stripper acceleration with even higher charge states. Beam acceleration up to 11.4 MeV/u and transport to SIS18 is the next step to confirm high intensity operation in the SIS18. Applying high density fast pulsed H_2 gas cell operation about 60% higher stripping efficiency reduces the requirements for HSI performance accordingly. The HSI now has to deliver just 12 emA (instead of 18 emA, if N_2 gas jet stripping is applied), thanks to the H_2 stripping device.

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