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STATUS OF THE HYDROGEN GAS STRIPPER AT THE UNILAC AT GSI

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Abstract

High intensity heavy ion beams are a main constituent of the FAIR research program. They will be provided by the UNIversal Linear ACcelerator UNILAC via the high current injector HSI. Generated in high current sources, these ions originally have low charge states. To allow for efficient acceleration in the UNILAC and SIS18, a gas stripper is located at the end of the HSI to reduce the mass-to-charge ratio below 8.5. An effort has been made to enhance the stripping by introducing hydrogen instead of nitrogen as stripping target, thereby increasing the stripping efficiency by up to 60% for ^{238}U. The main focus of the project is now on transforming the experimental setup into a system suitable for regular operation. In 2022, the main effort was on the finalization of the technical and explosion safety concept, which had been thoroughly revised last year and was awaiting final risk assessment. As a result for the technical implementation of the explosion safety document, the gas valves used for gas injection had to be excluded as possible ignition source. This has been done at IBExU. The roots pumping station had to be exchanged for an ATEX certified version. These three measures are presented in this publication, concluding with an outlook on the next steps towards routine operation of the pulsed hydrogen gas stripper at GSI.

INTRODUCTION

The GSI UNILAC (UNIversal Linear ACcelerator) shown in Figure 1 will serve together with the heavy ion synchrotron SIS18 as a high current, heavy ion injector for the future FAIR (Facility for Antiproton and Ion Research). The ions will be provided by the high current injector HSI. A stripper, situated at the end of the HSI, is necessary to increase the low charge states of the heavy ions produced by the high current sources in order to enable further acceleration in the post-stripper DTL (Drift Tube Linac) of Alvarez type. The present stripper employs a continuous nitrogen gas jet as stripping target. Out of the charge state spectrum resulting from the stripping process, one charge state has to be separated for further acceleration. For heavy ions like uranium, this results in effective loss of up to 85% of the beam.

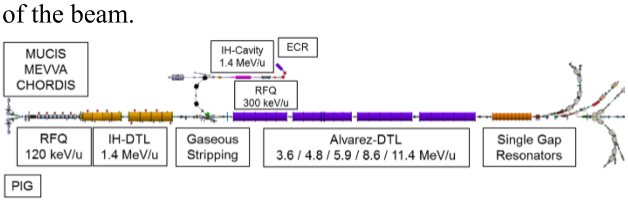

Figure 1: GSI - UNILAC with the gaseous stripping in front of the Alvarez DTL.

In order to increase the yield into the particular charge state desired, the introduction of hydrogen as stripping target was investigated from 2012 – 2016 [1, 2]. With hydrogen, in comparison to nitro, the width of the charge state distribution is reduced for heavy ions, thereby increasing the stripping efficiency e.g. for ^{238}U by approximately 60%. Additionally, for all ions an increase of the mean charge state can be achieved. This was demonstrated successfully in 2016 [1] and is shown in Figure 2. Introducing hydrogen into regular operation poses several challenges. Main concern is safety, since hydrogen is highly combustible. Apart from that, it is much more difficult to be extracted from the vacuum system. Finally, a fully automated setup suitable for regular operation has to be developed.

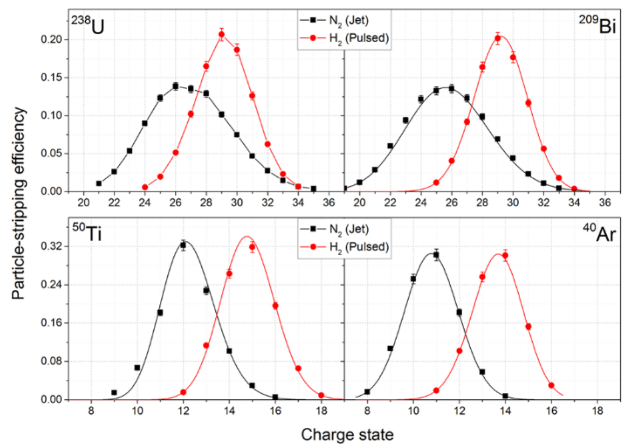

Figure 2: Comparison of the charge state distributions of ifferent ion species using nitrogen and hydrogen as stripping gas.

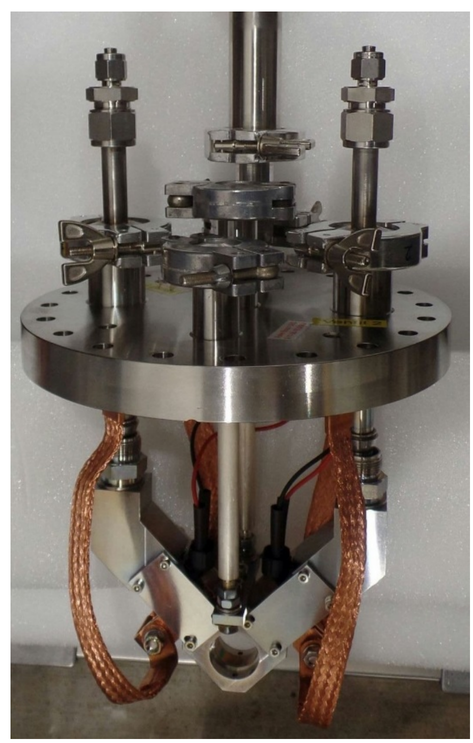

Figure 3: Photo of the latest stripper setup, accommodating two fast valves for gaseous media. The braided copper strips are installed for passive cooling of the valves.

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The gas stripper setup had been developed in the course of the original investigations [2]. It exploits the low duty factor of the UNILAC in order to reduce the gas load by delivering only short pulses of high gas density synchronised with the beam pulse. This was realised by using a fast injection valve. The gas is injected into a stripping cell, which confines the highly volatile hydrogen. After the proof of principle, a dedicated project was initiated to devise the regular operation of this pulsed gas stripper. An extensive risk assessment had to be conducted and several risk mitigation measures to be developed. A test stand was set up to investigate the properties of the valves under worst case conditions. The liquid fuel injection valve initially chosen proved unsuitable for prolonged operation with hydrogen [3]. Consequently, the type of the valves had to be changed and the setup adapted accordingly. A photo of the current pulsed gas stripper setup is shown in Figure 3. On the way towards the explosion safety document, different worst-case scenarios were investigated. The valves needed to be excluded as ignition source and the vacuum pumps used in the stripper section need to be exchanged for explosion safe devices.

EXPLOSION SAFETY DOCUMENT

The test and development system used for the proof-of-principle has to be consolidated and considerably extended in order to meet the safety requirements and enable reliable, fully automated, 24/7, and remotely controlled operation by the common accelerator staff. Extensions are specifically necessary for the automation and autonomous safety monitoring part. In 2022, the explosion safety document respecting these demands has been finalized. As part of this safety document many different gas flow scenarios have been simulated by CONSILAB [4]. Our special interest herein was the worst-case scenarios as well as operation feasibility despite the chosen safety measures. Two exemplary results are shown in Figure 4 and Figure 5. The simulations show the time dependent gas flow at the regulator (orange) and through the injection valve (red), as well as the resulting pressure just before the fast valves.

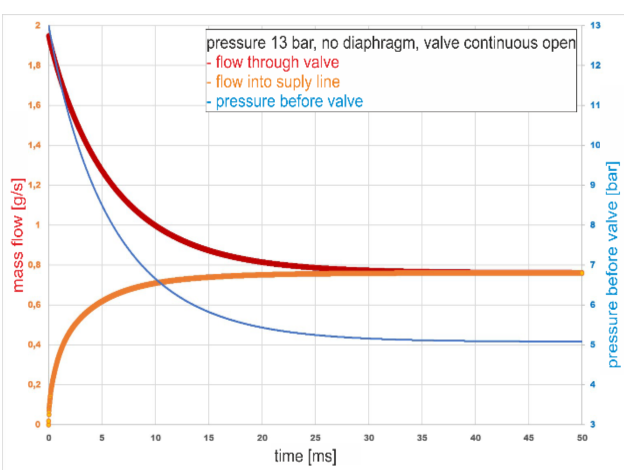

Figure 4: Simulation of a worst case failure scenario, assuming the fast injection valve does not close and hydrogen is flowing unhindered through the supply line.

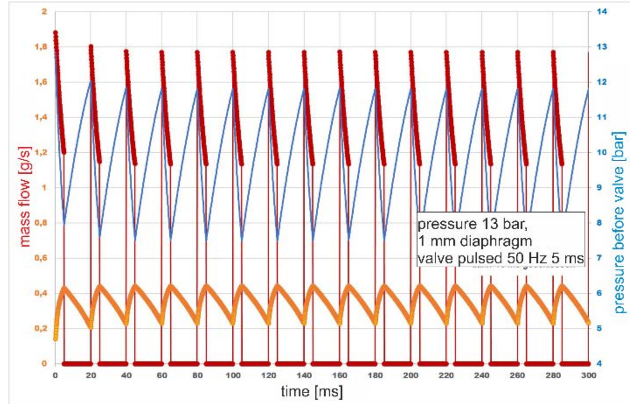

Figure 5: Simulation of a worst case operation scenario. (Figures by courtesy of Consilab)

EXCLUDING IGNITION SORCES

One crucial element of the safety concept is of course to know or even better rule out all possible ignition sources.

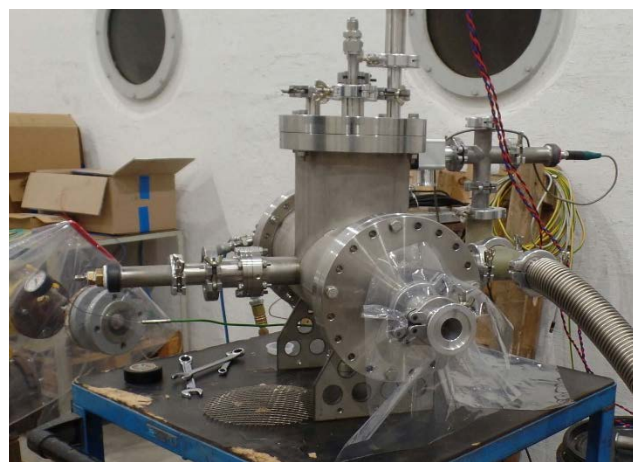

Figure 6: Ignition test setup at IBExU. Inside the chamber the valve setup as shown in Figure 3 was tested at 0.05, 0.1 and 1 bar most ignitable hydrogen-air mixture pressure.

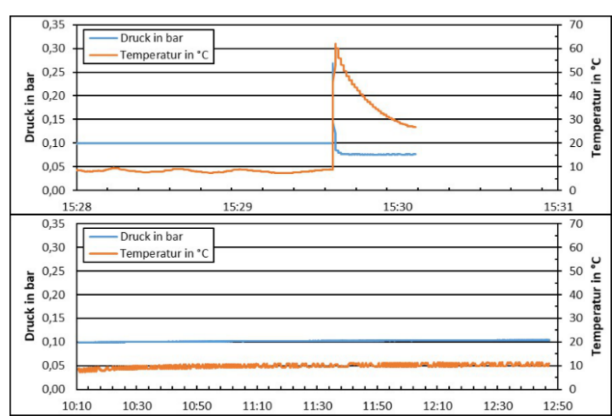

Figure 7: Measurement of the pressure (blue) and temperature (orange) in the vessel filled with most ignitable hydrogen-air mixture at 100 mbar during valve operation (lower). The mixture was deliberately ignited (upper) using a filament to check the correct mixture and functionality of the detectors. (Figures by courtesy of IBExU)

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Thus the fast injection valves that are not available in an ATEX certified version, needed to be excluded as possible ignition source in a certified test. This was done in an explosion safe bunker at the company IBExU Freiberg, Germany [5]. The test setup is shown in Figure 6 with the valves mounted exactly the same way as in the accelerator inside a vacuum chamber comprising a bursting diaphragm that allowed to adjust the most ignitable hydrogen-air mixture pressure. For pressures below atmosphere, it was not clear whether the detection of temperature and pressure is working sufficiently, thus a forced ignition by filament was used and detected as shown in Figure 7. For the actual valve test, the filament was replaced by the valve setup shown in Figure 1. The valves were then simultaneously operated for 2.5 h using repetition rates, voltages and currents with a safety margin above the routine operation values. As clearly visible, no ignition has been detected and the valves are excluded as possible ignition sources.

ATEX ROOTS PUMPING STATION

Figure 8: Photo of the ATEX roots pumping station during the Factory Acceptance Test FAT at Pfeiffer, Aßlar.

In fact, the main concern about explosion safety starts after the vacuum vessel with the compression of the gases by the pumps. For this reason, all pumps connected to the differential pumping of the stripper section, needed to be exchanged the new ATEX roots pumping station with a pumping speed above 8000 m^3/h at a pressure of 0.1 mbar, reaching a final pressure better than 10^{-03} mbar. The pumped media are hydrogen and nitrogen (up to 100%) and mixtures hereof. The whole pumping station is certified ATEX 3G IIC T3 inside.

SUMMARY AND OUTLOOK

The experimental setup for pulsed hydrogen gas stripping at GSI is transformed into a system suitable for regular operation. Last year, a giant leap toward realization was done by finalizing the explosion safety concept. As a result of this explosion safety document, necessary steps were realized, such as excluding possible ignition sources and exchanging hazardous equipment like non ATEX certified pumps.

Yet there are still three major steps toward routine operation missing. The gas handling needs to be automatized and included into the UNILAC control system. As for the FAIR project, the control system will be anyway replaced as part of the control system upgrade project. The layout of the gas handling cabinet has been worked out and currently companies are contacted to prepare tendering. Last but not least the pumped hydrogen needs to be diluted before it is fed into the GSI vacuum exhaust air installation. For this reason, we are in contact with different companies to tender a design study for a passive and thus failsafe mixing chamber. The main concern herein is the extreme bandwidth in hydrogen flow that such a system needs to cover.

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