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ON THE UNILAC PULSED GAS STRIPPER AT GSI

P. Gerhard*, M. Maier
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

Abstract

The UNILAC (UNIversal Linear ACcelerator) will serve as injector linac for heavy ion beams for the future FAIR (Facility for Antiproton and Ion Research), with the commissioning being anticipated in 2025. One of the crucial steps in the course of acceleration along the UNILAC is the stripping of the ions by a gas stripper in front of the main linac. Its efficiency is decisive in reaching the intensities required and may be increased by more than 50% by introducing hydrogen as stripping target, instead of the nitrogen used so far. This requires the stripper to be operated in a pulsed mode, since otherwise the pumping speed is not sufficient to maintain suitable vacuum conditions. The proof of principle was demonstrated in 2016. A dedicated project aims for a setup suitable for routine operation. Main issues are safety, reliability and automated operation. This project started in 2016, the realisation coming within the next few years. Recently, systematic measurements on the properties of the valves and their impact on the properties of the stripping target were carried out in order to specify proper operating parameters.

INTRODUCTION

The GSI UNILAC (UNIversal Linear ACcelerator) together with the heavy ion synchrotron SIS18 will serve 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 (very) low charge states of the heavy ions produced by the high current sources in order to enable further acceleration in the poststripper 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 the loss of up to 85% of the beam.

In order to increase the yield into the particular charge state desired, the introduction of hydrogen as stripping target was investigated from 2012–16. With H_2, in comparison to N_2, the width of the charge state distribution is reduced for heavy ions, thereby increasing the stripping efficiency e. g. for ^{238}U by approximately 50%. Additionally, for all ions an increase of the mean charge state can be achieved. This was demonstrated successfully in 2016 [1–3].

Introducing H_2 into regular operation poses several challenges. Main concern is safety, since hydrogen is highly combustible. Apart from that, it is much more difficult to extract from the vacuum system. Finally, a fully automated setup suitable for regular operation has to be developed.

A modified gas stripper setup had been developed in the course of the original investigations [1]. 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 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 gases [4]. Consequently, the type of the valves had to be changed and the setup adapted accordingly. The current pulsed gas stripper setup is shown in Fig. 1.

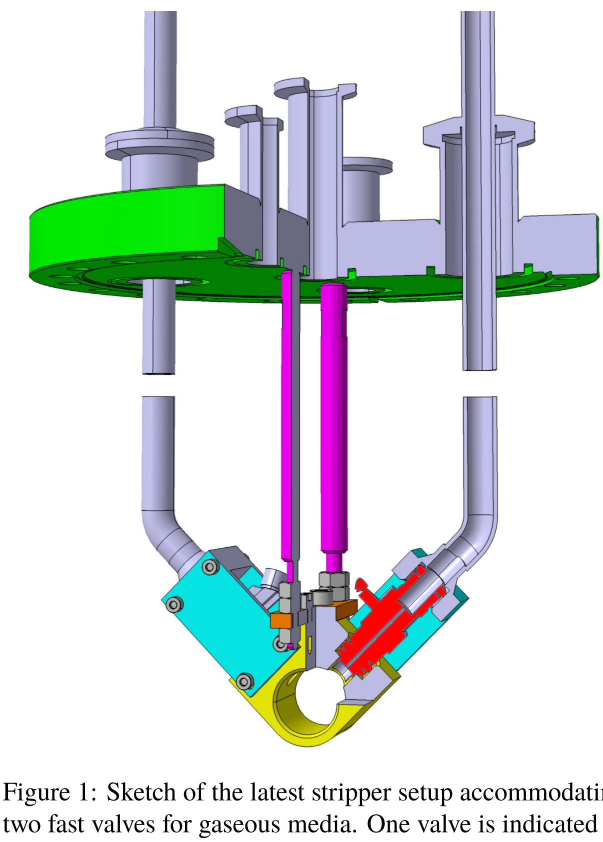

Figure 1: Sketch of the latest stripper setup accommodating two fast valves for gaseous media. One valve is indicated as cross section in red. Gas supply is from top via the tubes (grey). After injection into the accelerator vacuum, the gas is confined within the interaction zone in the yellow tube at the bottom, which surrounds the beam axis.

* p.gerhard@gsi.de

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SYSTEM DESIGN

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. An overview of the current overall system design is given in Fig. 2.

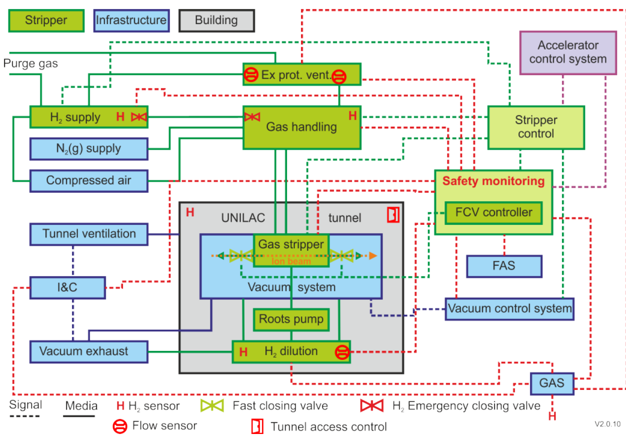

Figure 2: Simplified schematic overview of the current gas stripper system design. Green: specific parts of the gas stripper system, red: safety devices, blue: common infrastructure, violet: accelerator control system, grey: UNILAC accelerator tunnel building.

The further need for development is concentrated on the control logic and specific safety solutions. For the test setup, only minimal control logic was established, leaving most of it to manual operation. The same is true for the safety monitoring, which merely consisted of an elementary interlock. The components to be developed are in detail

- the stripper control: a PLC based control of all specific devices needed to operate the gas stripper and an SCU based controller to enable remote control via the accelerator control system, including an integrated programmable timing receiver,
- the safety monitoring system: monitor the proper status of all parameters and devices (stripper and infrastructure) needed for safe operation of the stripper, initiate emergency measures in case of alarms (e. g. shutdown hydrogen operation),
- the gas handling: adjust the operating pressure of stripper gases according to operational requirements and provide all functionalities to ensure proper and safe gas handling, and
- the H_2 dilution: dilute the exhaust H_2 with air to a safe level before disposal via the common, non explosion protected vacuum exhaust ventilation.

The following parts are required to be installed, but need only little development efforts:

- H_2 supply,
- dedicated, explosion protected ventilation for gas bottle and gas handling cabinets,
- explosion protected roots pump station,
- fast closing valves (FCV) and controller,
- cabling and piping.

The pulsed stripper system will make use of the following GSI infrastructure facilities or monitor their proper operating status:

- N_2(g) supply for stripper and purge gas,
- compressed air for valve actuators,
- accelerator vacuum system and its dedicated control system,
- several ventilation systems and their I&C equipment,
- gas alarm system (GAS), and
- fire alarm system (FAS).

SAFETY ASPECTS AND MEASURES

The safety of the H_2-operation is generally based on the fact, that the gas and vacuum system are closed during regular operation and contain only H_2 (and N_2), but no O_2 or other oxidising gases. Explosive mixtures can only occur when H_2 and air get in contact by failures. For the pressurised H_2 supply up to the fast injection valves, this would happen by H_2 leaking from the gas devices to the outside, which can be sufficiently excluded by standard technical provisions. For the remaining part of the stripper facility being under vacuum, an air leak in the vacuum system could lead to an explosive mixture inside. This can be excluded to a large extent for the stripper itself, but not completely for the vicinity of the stripper. Therefore, additional safety measures had to be devised. Primarily, the vacuum pressure in the stripper is monitored. As long as the pressure is below certain limits, no explosion can occur or any explosion can be contained inside the vacuum vessel, posing no hazard to the environment. For regular operation, both limits can be maintained. A pressure rise beyond the limits would be a clear indication of a failure, and H_2 operation would be shut down immediately. This is augmented by fast closing valves or shutters, which will be installed at both ends of the stripper section. If a vacuum leak occurs outside the stripper, these valves will close before the pressure in the stripper rises above the safety limits.

The measures mentioned can provide for safe operation in the stripper, but this does not hold true for the roots pump station, where the exhaust gas from the stripper is compressed up to atmospheric pressure. Therefore, this pump station will be upgraded to an explosion protected station. From here, the exhaust is handled by a dedicated vacuum exhaust ventilation system, which incorporates very fine particle filters for radiation protection reasons. This ventilation is not explosion protected. Therefore, the H_2 has to be brought into a hazard-free state before passing it into the ventilation system. Several methods were investigated, and finally a simple dilution with air was chosen. A suitable device is still to be designed, but technically feasible.

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To enhance the safety inside the stripper further, possible sources of ignition and their elimination were assessed. The vacuum gauges of Pirani type will be exchanged by capacitive or explosion protected ones. Ignition by the ion beam will be eliminated by connecting the fast beam chopper to the vacuum monitoring, shutting down the beam within a few ms after a pressure rise. This is assisted by the fast closing valves, which will prevent the beam physically from entering the stripper within 15 ms after the alarm. Finally, the risk of overheating of the fast injection valves, which get heated by the ohmic losses of the coil current, had to be tackled. Under *intended* operating conditions, cooling of the valves is provided by the gas flowing through the valve. This cannot be relied upon, since the gas flow is governed by the target density needed for proper stripping, which may be much lower than the design gas flow of the valve. The heat load had to be minimised not only because the valves would otherwise pose a source of ignition, but they would also fail to operate, as demonstrated at the test stand. Still, a backup cooling employing thermal conduction had to be attached to keep the valve temperature within acceptable limits under all operational and worst case conditions.

VALVE PROPERTIES

With the pulsed operation of the stripper, time was introduced as a new parameter. The temporal properties of the valves and the gas target have to be known in order to operate the stripper safe, reliable, efficient and with minimal gas load. A comprehensive test programme was carried out at a dedicated test stand, as testing time at the accelerator is scarce. These tests are limited to nitrogen operation due to the situation at the test stand. All tests with hydrogen have to be carried out at the accelerator. The test programme mainly dealt with electric parameters and gas throughput for various operating scenarios, aiming to reduce the thermal load on the valve coil and deriving data for the risk assessment. The valves are operated by a specialised fast magnetic valve controller applying a programmable voltage-current-profile. This profile was optimised for minimal thermal load, which is predominantly determined by the hold current applied to keep the valve open during the beam pulse. For short pulses, the much higher current during the short opening phase comes into play.

The detailed temporal behavior of the valves, the gas flow and the development of the gas target was the main topic of several accelerator experiment beam times. Time resolved data was acquired using the beam pulse to probe the gas target. However, with this approach only the integral properties of the valve and the gas target are accessible. Both argon and uranium beams were applied. Argon can be provided easily with long, stable pulses. Uranium is available with short pulses and less stability only, but is more sensible to variations of the target. Figure 3 shows a typical result of a measurement using a long argon beam pulse. The duration of the gas pulse was adjusted such, that the resulting target flattop just fits within the beam pulse and can be probed with a single shot. The delayed reaction of the gas target with respect to the electrical actuation of the valve is clearly visible for opening and even more pronounced for closing of the valve. The build up of the gas target starts approximately 250 µs after voltage is applied to the valve. After 4 ms the coil current is quickly purged by applying a high negative voltage to the valve. After that, it takes about 600 µs for the gas target to diminish. In between, the gas target shows a stable flattop, indicating that the hold current and the gas supply are sufficient.

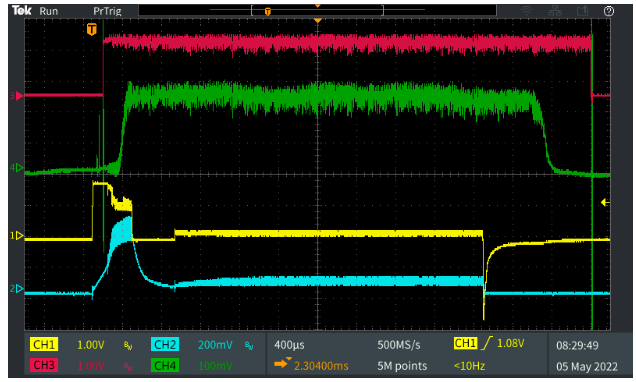

Figure 3: Oscilloscope screenshot showing the stripping of Ar^{2+} ions with the pulsed gas stripper using H_2 as stripping target. Shown are the current of the incoming beam (red) and the stripped Ar^{12+} beam (green), as well as the voltage (yellow) and current (cyan) applied to the valve.

STATUS AND OUTLOOK

The final risk assessment and verification of the conceptual technical design report is in progress and will be finished end of the year. Basic infrastructure like a safety cabinet for hydrogen gas bottles, an explosion safe cabinet ventilation, gas pipes, cabling, nitrogen and compressed air supply has already been procured and installed. The operating parameters and conditions for the pulsed stripper have been determined at the test stand, fixed and finally verified in a machine beam time in May this year. The explosion protected roots pump station has been ordered for delivery in spring next year. Its installation and commissioning is scheduled to be completed before start of the beam time in summer 2023. A safety examination of the injection valves is planned for autumn of this year. The specifications for the remaining parts of the gas stripper system are prepared and will be released after the final risk assessment. The procurement of the hardware is foreseen to be concluded until end of 2024. The in-house development of the front end and application level software and the data supply hierarchy for the accelerator control system are to be accomplished accordingly. Installation and commissioning of the whole gas stripper facility is scheduled to be completed before the beam time 2025, which is planned to start in summer. Finally, the successful supervision by a notified body is a prerequisite for the hydrogen operation of the gas stripper.

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