Nuclear Instruments and Methods in Physics Research A 863 (2017) 20–25

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Applications of the pulsed gas stripper technique at the GSI UNILAC

P. Scharrer [a,b,c,*], W. Barth [a,b], M. Bevcic [b], Ch.E. Düllmann [a,b,c], P. Gerhard [b], L. Groening [b], K.P. Horn [b], E. Jäger [b], J. Khuyagbaatar [a,b], J. Krier [b], H. Vormann [b], A. Yakushev [a,b]

[a] Helmholtz Institute Mainz, Johannes Gutenberg-Universität Mainz, Mainz 55099, Germany
[b] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, Darmstadt 64291, Germany
[c] Johannes Gutenberg-Universität Mainz, Saarstr. 1, 55128 Mainz, Germany

ARTICLE INFO

Article history:
Received 27 February 2017
Received in revised form
2 May 2017
Accepted 10 May 2017
Available online 10 May 2017

Keywords:
GSI
UNILAC
Gas stripper
Pulsed
Heavy-ion

ABSTRACT

In the frame of an upgrade program for the GSI UNILAC, preparing it for the use as an injector system for FAIR, a pulsed gas stripper cell was developed. It utilizes the required low duty cycle by applying a pulsed gas injection instead of a continuous gas inlet. The resulting lower gas consumption rate enables the use of low-Z gas targets over a wide range of stripper target thicknesses. The setup enables an increased flexibility for the accelerator by allowing the gas stripper to be used in time-sharing beam operation matching the capabilities of the GSI UNILAC like the acceleration of different ion beams in quasi-parallel operation. Measured charge state distributions of ^{238}U, ^{50}Ti, and CH_3 beams on H_2 and N_2 gas highlight the benefits of the pulsed gas stripper cell for the accelerator operation and performance.

1. Introduction

The GSI Universal Linear Accelerator (UNILAC) will be used as part of an injection system of the future Facility for Antiproton and Ion Research (FAIR) [1]. In order to meet the corresponding high requirements for beam injection in terms of beam intensity and beam quality, an upgrade program for the UNILAC is ongoing [2]. A new setup for the gas stripper at 1.4 MeV/u beam energy was developed, aiming for an increased yield into the desired charge state (e.g., 28+ for ^{238}U) [3].

The new setup is optimized for the low duty cycle required for FAIR. Accordingly, the previously used continuous gas jet was replaced by a pulsed gas injection. This reduces the gas load for the differential pumping system. Increased gas densities during the beam pulse transit and, therefore, increased effective target thicknesses for the stripping process are achieved in this way. This enabled the practical use of low-Z gas targets (H_2 and He) with sufficiently high target thicknesses to reach equilibrium charge state distributions [4]. The equilibrium charge state distribution constitutes the maximum achievable stripping efficiency for the highest possible charge states for each beam-target combination. Therefore, it is of high importance for the gas stripper performance [5].

By using the pulsed gas stripper cell with H_2 gas, the maximum stripping efficiency could be increased by about 50% (compared to the jet-based system). With this, a new U^{28+}-intensity record was achieved at GSI [6]. For standard operation at the UNILAC, the gas stripper is in use for a wide range of ion projectiles (Z=1–92). In previous measurement campaigns, the pulsed gas stripper was tested with several different ion beams, including U, Ti, and CH_3.

2. UNILAC time-sharing beam operation

A schematic setup of the GSI UNILAC is shown in Fig. 1 with a typical example of the time-sharing beam operation, which will be explained later in more detail. Ion beams are delivered by three individual ion source branches from various available ion sources [7]. An Electron Cyclotron Resonance (ECR) ion source provides for highly charged ion beams (e.g. ^{48}Ca with charge state 10+ in Fig. 1). Followed by a Radiofrequency Quadrupole (RFQ) accelerator and an Interdigital H-type (IH) accelerator it comprises the High Charge Injector (HLI) [8], which delivers ion beams directly to the Alvarez-type Drift-Tube Linac (DTL) accelerator [2], without passing the gas stripper. A Vacuum Arc Ion Source (VARIS) and a Penning Ionization Gauge (PIG) ion source are used to produce heavy ions such as ^{238}U and ^{197}Au with a relatively low charge state. For, e.g., ^{238}U, the ion beams are produced with charge state 4+, which enables a high yield from the ion source. Molecular beams, like CH_3, can be produced in a MUlticusp Ion Source (MUCIS) utilizing a different extraction system [9]. These beams are accelerated in the High Current Injector (HSI) [10], mainly

* Corresponding author at: Helmholtz Institute Mainz, Johannes Gutenberg-Universität Mainz, Mainz 55099, Germany.

http://dx.doi.org/10.1016/j.nima.2017.05.015
0168-9002/

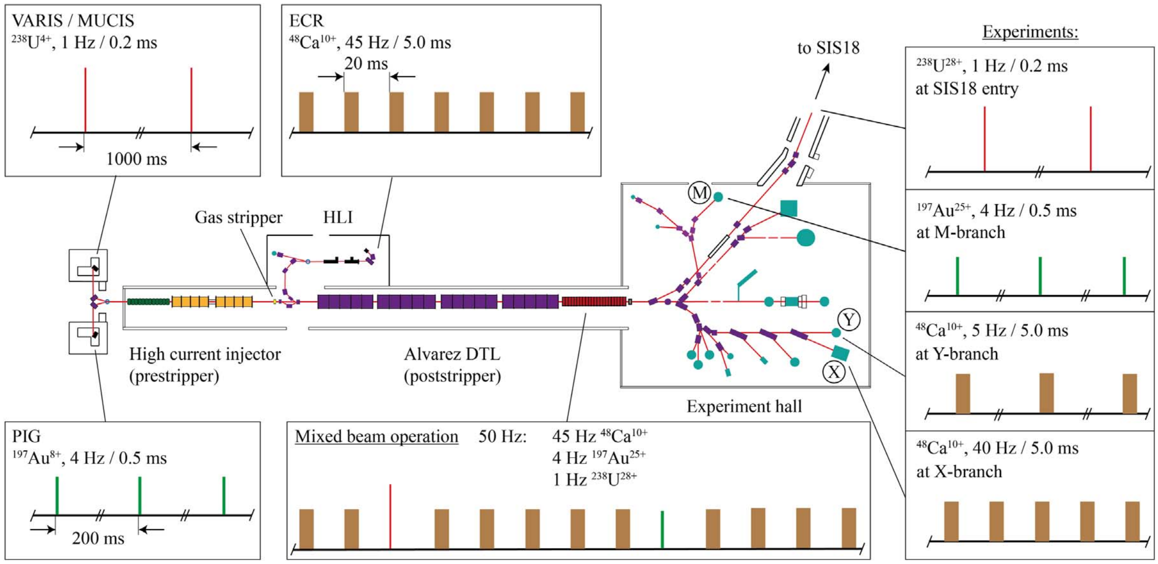

Fig. 1. Schematic of the GSI UNILAC with a typical example of the time-sharing beam operation; for more details, see text.

comprising an RFQ and two IH-DTL sections, from 2.2 keV/u up to 1.4 MeV/u beam energy before reaching the gas stripper section.

In the gas stripper, the charge state of the ions increases due to charge-changing processes in collisions of ions with gas particles [11]. The final equilibrium charge state distribution is independend of the initial charge state of the ion beam. Only one charge state is selected for further acceleration. Behind the stripper section the ion beams are injected into the Alvarez DTL, enabling the acceleration up to 11.4 MeV/u beam energy. The Alvarez DTL comprises five individually controlable accelerator tanks, enabling various different beam energies, as demanded by the beam-requesting experiments. Behind the Alvarez, the ion beams can be delivered to experiments in the adjacent experiment hall or can be injected into the transfer line to the 18 Tm synchrotron SIS18 [12].

At the UNILAC, all RF-systems, transverse matching sections, and switching magnets, are operated in a pulsed mode allowing for a time-sharing beam operation [13]. This enables the UNILAC to deliver several different ion beams with varying beam settings quasi-parallel to different experiments. The individual sets of ion-beam parameters, namely ion type, beam energy, intensity, pulse length, and repetition rate, are labeled as so-called "virtual accelerators". The maximum total repetition rate is fixed to 50 Hz. The beam pulse length is adaptable from 10 μs up to 5 ms, however a beam pulse length >1.2 ms is only possible for ions with $A/q \leq 26$ due to limitations of the HSI. Thus, the minimum pause time between two beam pulses is 15 ms. Independent on the beam settings the ion sources are operated at a fixed repetition rate, depending on the type of source and the mass-to-charge ratio of the required beam. In time-sharing beam operation one ion source can deliver ion beams to multiple virtual accelerators.

A typical example for time-sharing beam operation is shown in Fig. 1 for ^{238}U, ^{197}Au, and ^{48}Ca ion beams, provided for different experiments at the same time. All beam targets, like experiment locations and beam dumps, are subdivided into branches and can be selected as a destination for a virtual accelerator. ^{238}U is mainly used for injection into the SIS18 at low repetition rate, ^{197}Au is delivered to experiments behind the UNILAC in the M-branch, while the ^{48}Ca beam is typically desired with a high duty cycle, e.g., for super-heavy elements research at the SHIP [14] (Y-branch) or TASCA [15] (X-branch) experiments.

The routinely used continuous N_2 gas-jet stripper does not feature multiple gas-supply lines. Additionally, the pressure regulation is not fast enough to change the back-pressure on the nozzle in between beam pulses. Therefore, the N_2 gas-jet stripper operates only in a continuous mode. Sufficient target thicknesses for low-Z gas targets to acquire equilibrium charge state distributions can not be reached with the N_2 gas-jet stripper due to a high gas load for the pumping system [16].

3. Pulsed gas stripper cell

The setup of the pulsed gas stripper cell is shown in Fig Fig 2 and is described in detail in [5,17,18]. The pulsed gas injection is realized by pulsed gas valves, normally used in automotive applications. They open shortly just before a beam pulse enters the

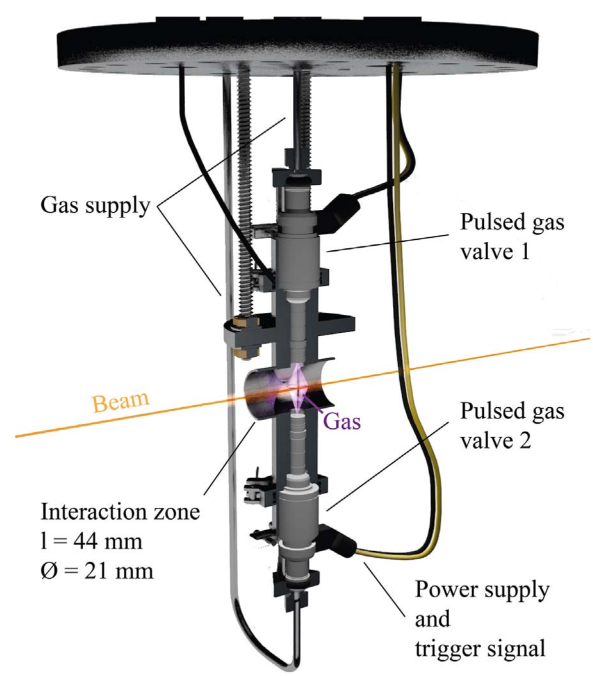

Fig. 2. Schematic model of the setup of the pulsed gas stripper [17]. The gas target is created in an interaction zone that is enclosed by a short tube. Two pulsed gas valves, which are synchronized with the beam pulse timing, are used as gas inlet and can be used separately or in combination.