HIGH CURRENT PROTON AND CARBON BEAM OPERATION VIA STRIPPING OF A MOLECULAR BEAM AT GSI UNILAC

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Abstract

The experimental program of the future facility for Antiproton and Ion Research (FAIR) project requires a high number of cooled anti-protons per hour [1]. The FAIR proton injector linac has to deliver a 70 MeV, 35 mA pulsed proton beam at a repetition rate of 4 Hz. During recent machine investigations at GSI a high current proton beam was achieved in the Universal Linear Accelerator (UNILAC) [2]. In preparation for this the ion source was equipped with a newly developed 7-hole extraction system and optimized for single charged hydrocarbon beam (isobutane gas) operation. This beam was accelerated to 1.4 MeV/u and cracked in a new pulsed gas stripper into protons and charged carbon ions. The new stripper setup injects high density gas pulses synchronous with the transit of the beam pulse close to the beam trajectory. With this setup a proton (up to 4.3 mA) as well a carbon beam (up to 9.5 mA) intensity record at beam energy of 1.4 MeV was achieved. The proton beam was accelerated up to 3.6 MeV/u inside the first Alvarez-section with full transmission. The paper will present beam measurement in comparison to the former beam investigations using a 2 mA proton beam in the entire UNILAC.

INTRODUCTION

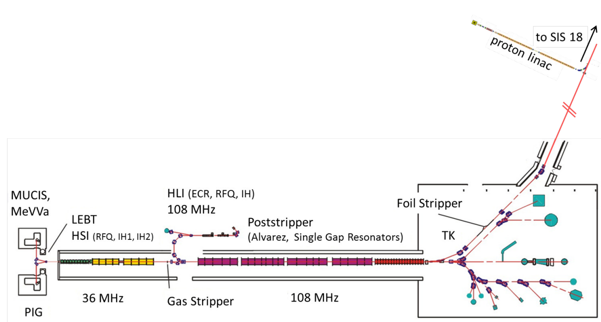

Figure 1: Schematic overview of the GSI UNILAC and FAIR proton linac.

The GSI (Gesellschaft für Schwerionenforschung, Darmstadt, Germany) comprises two beam paths to the UNILAC (Fig. 1): High Current Injector (HSI) and High Charge state Injector (HLI). Two ion sources deliver the ion beam to the HSI Radio Frequency Quadrupole (IH-RFQ). The RFQ accelerates the beam up to 120 keV/u, the following Interdigital H-structure Drift Tube Linac (IH-DTL) has a final HSI energy of 1.4 MeV/u at a resonance frequency of 36.136 MHz. In the stripper section a dipole chicane is installed after the supersonic N_2-gas jet stripper for charge state separation [3]. At the HLI an Electron Cyclotron Resonance (ECR) ion source of CAPRICE type provides highly charged ions for an RFQ IH-DTL combination with a frequency of 108.408 MHz to be injected into the main DTL without stripping. In the poststripper section five Alvarez DTLs with a resonance frequency of 108.408 MHz provides for acceleration up to 11.4 MeV/u ($\beta = 0.156$). The HLI and HSI can serve for the poststripper linac in a time sharing mode. The beam will be delivered either via transfer line (TK) to the synchrotron SIS 18 or to the experimental area. In the TK a foil stripper can be used optionaly with a charge state separator chicane.

The FAIR proton injector comprising with six room temperature Crossbar H-mode (CH) structures provides for an energy of a 70 MeV (70 mA) beam for the SIS 18 injection [4]. The injector frontend comprises an ECR ion source with a short LEBT, an RFQ will accelerate the proton beam to 3 MeV. The first CH-section achieves an energy of 35 MeV after three RF coupled CH-cavities. The p-Linac injector delivers the protons to the TK and adjacent to the SIS 18. The main parameters of the p-Linac are listed in Table 1. The single and coupled CH-cavities are cost efficient, robust and compact in its transversal and longitudinal dimensions at a frequency of 325 MHz [5]. After the final tuning and

Table 1: Parameters of the FAIR Proton Injector

Parameter	Unit	Value
Final beam energy	MeV	70
Beam energy (RFQ out)	MeV	3
Beam energy 1. section	MeV	35
Beam current	mA	Up tp 70
Protons per pulse		8×10^{12}
Repetition rate	Hz	4
Resonance frequency	MHz	325.224
Number of single CH cavities		3
Number of coupled CH cavities		3

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RF preparation of the coupled CH-cavity prototype the RF conditioning has been already startet.

At the existing UNILAC a high intensity proton investigation program was successful started in 2014 [6]. In this program the molecule operation with CH_3^+ was established; a proton beam current in the stripper section of 3 mA was reached. The new advanced isobutane molecule operation in 2015 applying the new pulsed gas stripper proton and carbon beam intensity was significant increased. The optimization of the ion source and the UNILAC as well as the new pulsed gas stripper is discribed below.

MOLECULAR BEAM

The high current ion source MUCIS with the standard extraction system (accel-decel with 13 apertures, ∅ 3 mm each) was used in machine experiment in 2014 [7, 8]. For the machine experiment in 2015 another extraction system (accel-decel with 7 apertures, ∅ 5 mm each) has been tested to optimize the beam extraction and the beam quality in the LEBT. The distance between plasma and screening electrodes was shifted from 3 mm to 4.5 mm. With an optimized extraction system for isobutane gas operation a better beam quality was accomplished, when the beam current remaining (Fig. 2) [7].

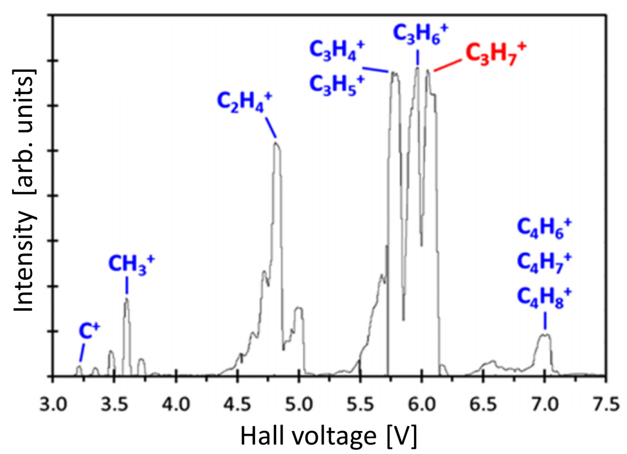

Figure 2: Measured mass spectra for isobutane-operation at the MUCIS ion source (taken from [7]).

PULSED GAS STRIPPER

With the newly developed pulsed gas stripper (Fig. 3) the beam intensity after the UNILAC High Current Injector could be increased [9]. The stripper setup injects high density gas pulses synchronous with the transit of the beam pulse close to the beam trajectory. The synchronization of the gas valve is initiated by a timing signal from the main accelerator control system. The gas valves open in the setup only when a beam pulse passes the gas stripper and closes immediately. The gas is injected into the stripper zone via a T-fitting, which is aligned centrical to the beam axis. The back-pressure on the gas inlet is free adjustable up to 12 MPa for each gas. A four stage differential pumping system (1200 l/s each) and a roots vacuum pump (2222 l/s), located directly on the main stripper chamber are used for the required vacuum. In an ion operation the electrons are stripped and the charge state distribution is increased. The presented molecule operation in this contribution will crack a hydrocarbon beam (isobutane gas) with the pulsed gas stripper into protons and charged carbon (Fig. 4). In CH_3^+-operation the molecule beam is cracked in one carbon and three protons; in $C_3H_7^+$-operation received three carbons and seven protons. In the stripper section the charge separation system is used to separate the proton from the carbon beam. A H_2-target at variable gas densities was used as a gas stripper target.

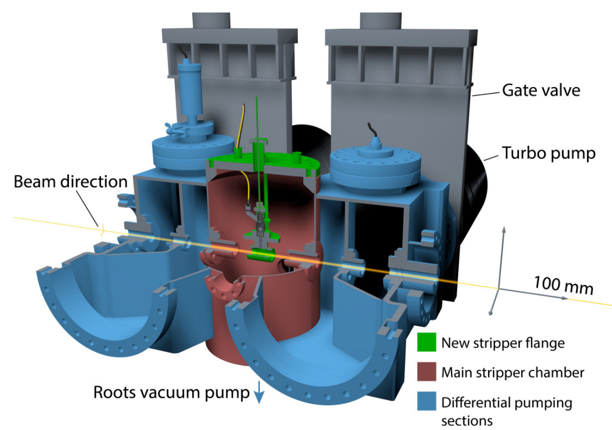

Figure 3: CAD model of the pulsed gas stripper. The T-fitting and the two gas valves (green) are mounted on a standard CF-flange.

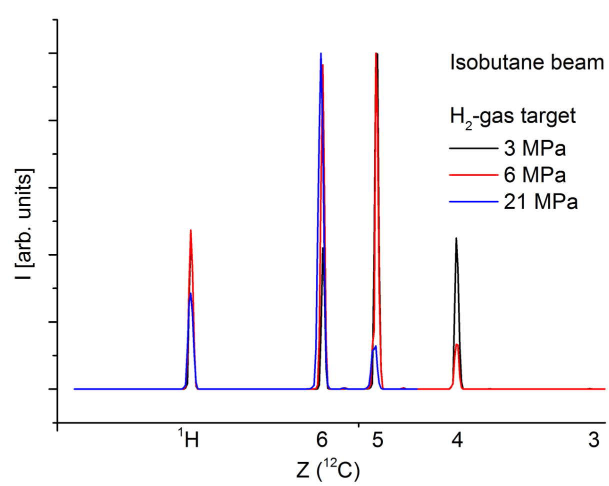

Figure 4: Measured gas stripper spectra of the $C_4H_7^+$-beam from the HSI; the carbon beam could be optimized for higher Z depending on the H_2-target density.

PROTON AND CARBON BEAM

The proton as well as the carbon beam emittance and transmission (isobutane beam: $C_3H_7^+$) was measured behind the pulsed stripper section. The new pulsed stripper

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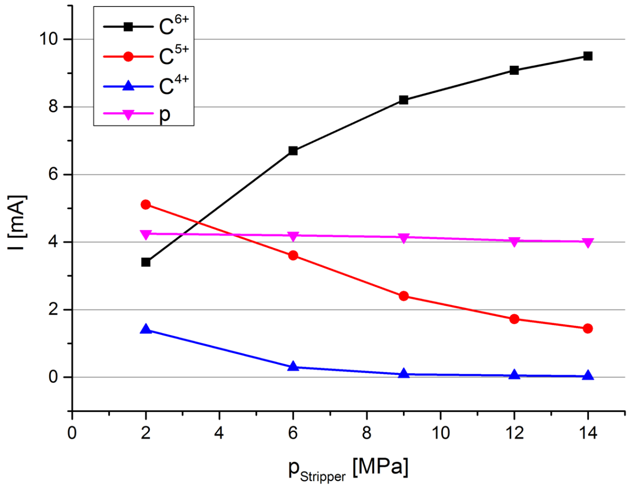

Figure 5: Measured beam current depends on the back-pressure of the gas inlet of the pulsed gas stripper; the proton beam intensity is independent on the gas pressure, while the carbon beam intensity is increased with the target density.

was used for the first time to crack and strip an isobutane molecule beam. The back-pressure of the stripper-gas (H_2) was selectable up to 12 MPa for a single valve. The beam current was measured depending on the back-pressure of the stripper-gas (Fig. 5) behind the stripper section at 1.4 MeV/u. The proton beam is independent on the stripper-gas pressure at 4 emA, while the carbon beam is very different. The carbon charge states are 4+, 5+ and 6+. The stripping efficiency decrease depend on the pressure to zero, for C^{5+} it increases of 60%, while for C^{6+} the efficiency increases up to 9.5 mA at the maximum back-pressure of 14 MPa. The proton beam was further accelerated (Fig. 6). For this machine experiment Alvarez 3 could not used and some drift tubes (transversal beam alignment) were offline. With these technical condition an excellent overall transmission of 75% was reached.

The high current transverse beam emittance was measured with high resolution behind the stripper section (Fig. 7). The isobutane beam was cracked into protons and carbon ions

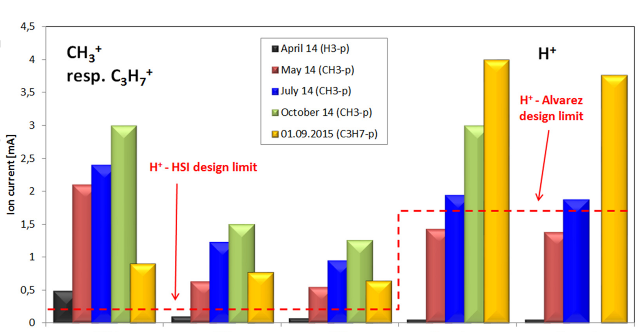

Figure 6: Measured beam current along HSI and Alvarez 1; the proton design limit was exceeded in the post stripper section.

with the pulsed gas stripper for different back-pressures of the gas inlet. The presented measurements using a back-pressure of 2 MPa and 14 MPa as the extrema of one gas valves. With this transversal beam emittance matching to the Alvarez was accomplished without any problems. The first Alvarez tank with high transmission, which is most critical due to space charge forces.

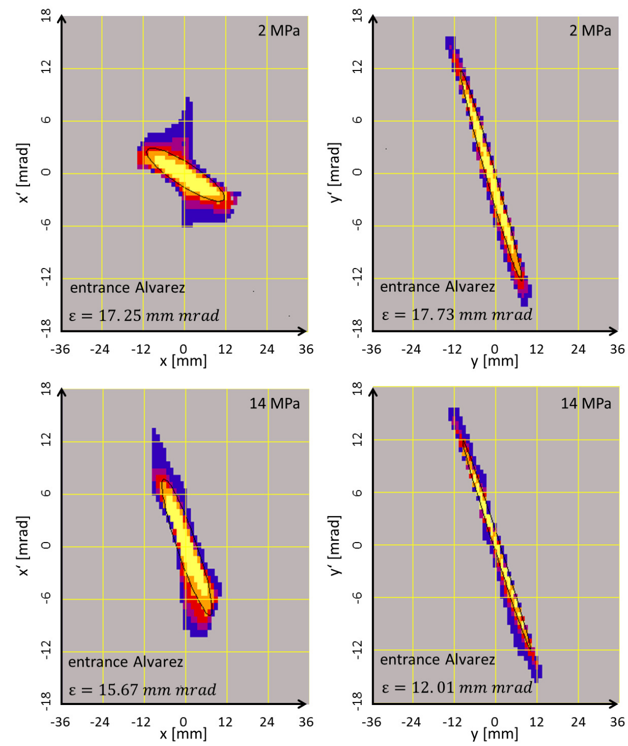

Figure 7: Measured high current proton beam emittance (isobutane beam: $C_3H_7^+$) at 1.4 MeV/u.

OUTLOOK

The existing UNILAC can be used for commissioning of the FAIR pbar chain and as a redundant high performance proton injector for FAIR. In combination with the prototype CH-cavity in the transfer line section a proton beam output energy of 24.2 MeV is proposed in [10].

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