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FURTHER DEVELOPMENT OF SC CW-LINAC AT GSI

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Abstract

Recently the first section of a standalone superconducting continuous wave heavy ion linac HELIAC (HElmholtz LInear ACcelerator) as a demonstration of the capability of 217 MHz multi gap Crossbar H-mode structures has been commissioned and extensively tested with beam at GSI. The demonstrator set up reached acceleration of heavy ions up to the design beam energy and beyond. The required acceleration gain of 0.5 MeV/u was achieved with heavy ion beams even above the design mass to charge ratio at maximum available beam intensity and full beam transmission. This contribution presents further development and optimization of the HELIAC machine at HIM/GSI.

INTRODUCTION

During the last decades the Mendeleyev periodic table of elements was significantly extended up to the nuclei Oganessyan (Og) with the charge number Z = 118 and the mass number A = 294. Fusion-evaporation reactions of the accelerated medium and heavy ions with the heavy-element targets are recently the most successful methods for the laboratory synthesis of Super Heavy Elements (SHE) [1]. Due to the very low crossections of such reactions, the events are extremely rare, what requires weeks of beamtime. Obviously, an increased projectile intensity, in the best case in continuous wave (CW) mode, should improve the SHE yield [2,3].

For this purpose heavy ion superconducting (SC) CW HELIAC is developed at GSI Helmholtzzentrum für Schwerionenforschung (GSI, Darmstadt, Germany) and Helmholtz Institut Mainz (HIM, Mainz, Germany) [4-6] under key support of Goethe-University Frankfurt (IAP, Frankfurt-am-Main, Germany) [7,8] and in collaboration with Moscow Engineering Physics Institute (MEPhI, Moscow, Russia) and Institute for Theoretical and Experimental Physics (ITEP, Moscow, Russia) [9,10].

The Superconducting RF technology, being one of the main features of the HELIAC project, allows for the extremely high accelerating gradient of about 7 MV/m. Therefore it provides for the compact and efficient machine (Fig.1), which is foreseen to be integrated into GSI accelerator complex.

Due to its advanced characteristics, the HELIAC stays well in line with other modern CW and SC linac projects at the leading accelerator centers [11]. The design, construction and operation of CW proton and ion linacs are crucial goal of accelerator development worldwide. A large scale facility [12-14], such as accelerator driven system or spallation neutron source, implements a high energy CW linac as an essential part. A medium energy SC CW linac could be used for a number of applications [15], as high productivity isotope generation, material science and boron-neutron capture therapy [16-18]. Therefore further elaboration of superconducting technology [19] and development of SC CW linacs is of high relevance for the accelerator community.

From other side, the HELIAC, being an unique machine, certainly takes its place among a number of modern accelerator activities at GSI, namely the high current heavy ion UNILAC (UNIversal Linear ACcelerator) [20-23], recently upgraded for FAIR (Facility for Antiproton and Ion Research at Darmstadt) [24,25], the proton linac for FAIR [26,27] and proton beams from the UNILAC [28,29], the heavy ion linear decelerator HITRAP (Heavy Ion TRAP) [30,31] and the advanced project LIGHT (Laser Ion Generation, Handling and Transport) for laser acceleration of protons and heavy ions [32,33].

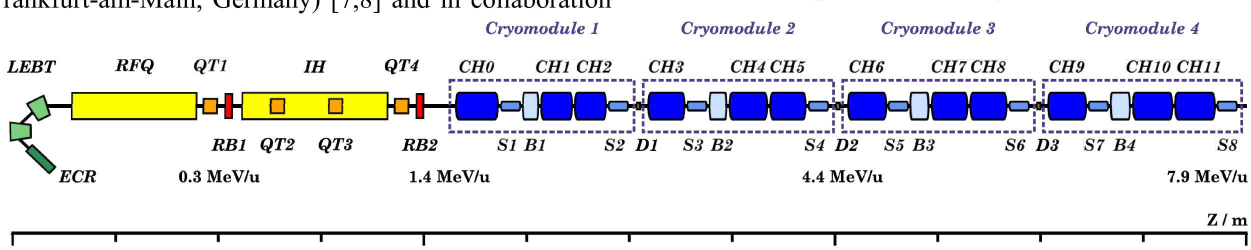

Figure 1: Conceptual layout of the heavy ion SC CW HELIAC with warm injector.

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SC CW DEMONSTRATOR AT GSI

The existing GSI High Charge State Injector (HLI) routinely delivers heavy ion beams to the UNILAC [34]. A dedicated transport line transfers beams from the HLI exit to the SC CW Demonstrator cave (Fig. 2).

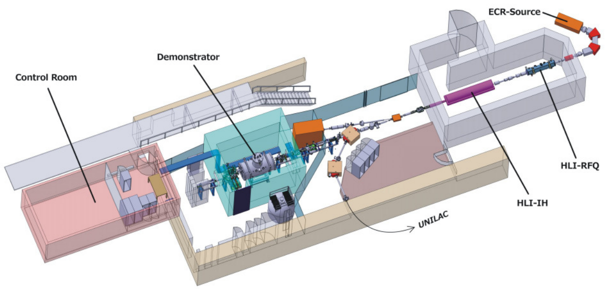

Figure 2: SC CW Demonstrator environment at GSI.

In July 2017 the SC CW Demonstrator, consisting of the 15-gap CH-cavity and two SC solenoids (Fig.3), has been successfully commissioned [4].

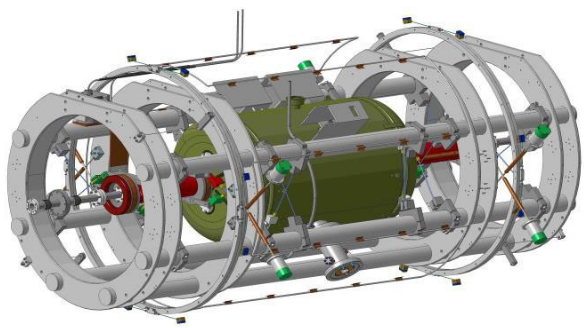

Figure 3: Demonstrator CH-cavity (CH0) with two SC solenoids inside the support frame.

The expected acceleration of heavy ions has been achieved (and even exceeded) with high beam intensity and full beam transmission (Fig.4).

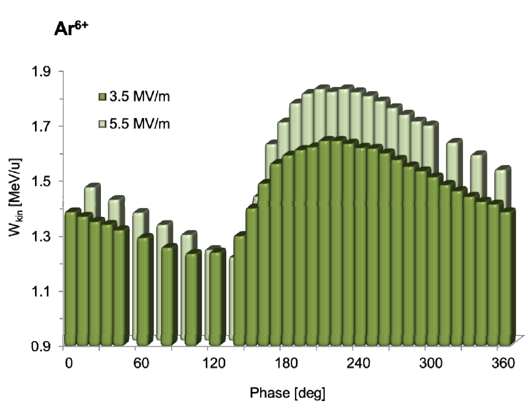

Figure 4: 2D-scan of Ar^{6+}-beam energy versus accelerating gradient and RF-phase (A/Z=6.7).

Besides beam energy measurements the bunch shape (Fig.5) was measured with Feschenko monitor [35]. An impressive small minimum bunch length is detected, sufficient for further matching to and acceleration in the next RF-cavities.

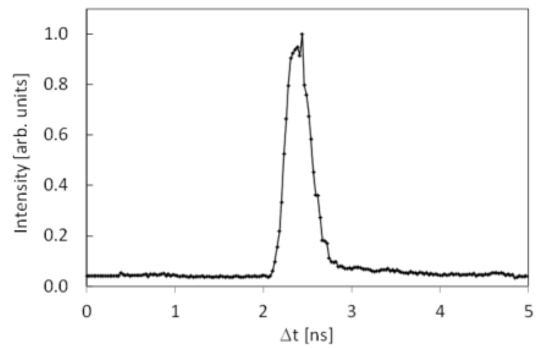

Figure 5: Measured bunch shape of fully matched Ar^{6+}-beam at the energy of 1.85 MeV/u.

With Ar^{6+} beam (A/Z=6.7), an energy gain above 0.5 MeV/u could be reached with an accelerating gradient of 6 MV/m. Therefore the successful RF- and beam testing with the 15-gap CH0 showed experimentally, that higher accelerating gradients can be achieved.

The construction of the CH1 and CH2 217 MHz CH-cavities started in December 2016. The CH1 was finished in March 2018, the CH2 in September 2018. Both cavities have identical geometry with the same constant beta profile and are designed to increase the mechanical stiffness and reduce the pressure sensitivity. The conservative design gradient is about 5 MV/m, which has to be achieved by eight accelerating cells [36].

The first test with low level RF power of CH1 at 4.2K at IAP has shown a very promising gradient of 9 MV/m. The first cryogenic test with CH2 is foreseen recently, as well as a possible test at 2K with both cavities. Additionally it is planned to perform an improved preparation of the cavities surface at the Helmholtz-Institut Mainz, after the construction of the clean room is finished.

SC CW HELIAC RECENT DESIGN

Recent HELIAC design (Fig. 1), revised from the original one [37], foresees twelve superconducting Crossbar H-cavities (CH), operated at 217 MHz and grouped in four modules (Fig.1). Each cryomodule equipped with three CH structures, two solenoids and a Spoke-type buncher for the longitudinal beam matching. The beam dynamics concept considers transverse beam focusing by superconducting solenoids with the magnetic field up to 9.5 T. The linac should provide for acceleration of ions with an energy of 1.4 MeV/u and mass to charge ratio up to A/Z=6 to output beam energies, smoothly varied between 3.5 MeV/u and 7.3 MeV/u [38].

In this context, a revision of the beam dynamics layout was recommended. Optimized cavity layouts resulted in modified voltage distributions; the cryomodule layout and intertank sections were specified in more details. The higher accelerating gradients lead to a more efficient design approach. Consequently, extensive beam dynamics studies are recently under consideration to optimize the layout with respect to the beam parameters (Fig. 6), as well as RF and mechanical characteristics.

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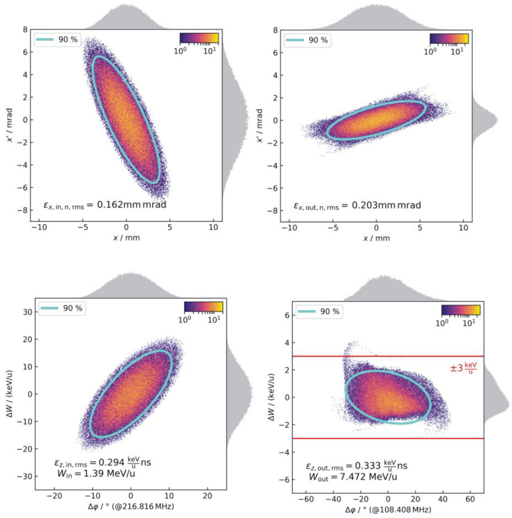

Figure 6: Input (left) and output (right) phase space distributions (applying max. accelerating gradient of 7.1 MeV/u): X-X' (top), φ-ΔW (bottom).

Applying the advanced beam dynamics layout for lower mass to charge ratios, significantly higher beam energies could be achieved (e.g. up to 14.6 MeV for a proton beam) [6,8]. The potential acceleration of heavy ions (A/Z up to 8.5) has been already confirmed by the simulations with dedicated software [39,40].

NEW HIM CLEANROOM

In order to treat and prepare HELIAC RF cavities, a new cleanroom facility has been built at the Helmholtz-Institut in Mainz. All tools and machines inside the cleanroom can handle cavities with up to 750 mm in diameter and with up to 1300 mm in length. In its ISO-class 6 and 4 zones, respectively it features a large ultrasonic and conductance rinsing bath, a High Pressure Rinse (HPR) cabinet (Fig.7) and a vacuum oven. For RF testing a concrete shielded area with sufficient liquid helium supply is located next to the cleanroom and the cryomodule assembly area [41].

Figure 7: High pressure rinse cabinet: view from ISO-6 access side for loading.

CONCLUSION

The new heavy ion SC CW HELIAC, conducted by HIM at GSI in collaboration with IAP, is fully in line with modern high efficiency CW linac projects, which are under development at different leading accelerator centers worldwide. In July 2017 the first superconducting 15-gap CH cavity, designed on the base of EQUUS beam dynamics [37], has been successfully commissioned at GSI with heavy ion beams.

Recent experience has been gained in design, fabrication and operation of SC CH-cavities and the associated components. A revision of the HELIAC layout with an increased accelerating gradient of the cavities has been specified with more details. This new design could provide beam acceleration for a wide range of different ions (protons to uranium) above the design beam energy, featuring the ambitious SHE program at GSI.

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