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STEPS TOWARDS A SUPERCONDUCTING CW-LINAC FOR HEAVY IONS AT GSI

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Abstract

A superconducting (sc) cw-Linac at GSI should ensure competitive production of Super Heavies in the future. Further R&D for this cw-Linac, a so called "Advanced cw-demonstrator", with maximal energy of 3.5 MeV/u is ongoing. As a first step, the demonstrator project with one sc CH-cavity is completed, the beam tests are performed mid-summer 2017. The completion of the "Advanced CW-Demonstrator" includes successive construction of at least one new cryogenic modules comprising three CH-cavities and two solenoids each. In this contribution the layout of the cryo module and the Helium distribution system are presented.

ORIGINAL LAYUOT

Providing heavy ion beams for the ambitious experiment program at GSI, the Universal Linear Accelerator (UNILAC) serves as a powerful high duty factor (25%) accelerator. Beam time availability for SHE-research will be decreased due to the limitation of the UNILAC providing a proper high intensity beam for FAIR simultaneously. To keep the GSI-SHE program [1] competitive on a high level, a standalone sc cw-linac in combination with the upgraded GSI High Charge State Injector (HLI) is planned to build. The Figure 1 shows a conceptual layout of cw-linac. This design, proposed more then eight years ago [2], contains nine superconducting (sc) Crossbar H-mode (CH) cavities.

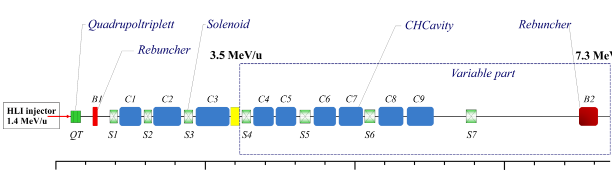

Figure 1: Original layout of cw-linac.

The beam with an energy of 1.4 MeV/u from HLI operating at 108.408 MHz, is transported through the line comprising of quadrupole lenses for transversal matching and rebuncher cavities for longitudinal matching to cw-linac. The multigap CH-cavities operate at double frequency of HLI and provide an effective accelerating gradient of 5.1 MV/m each. Seven sc solenoids with free beam aperture of 30 mm and magnetic field strength up to 9.3 T providing beam focusing. The first part of linac comprising of three CH multigap cavities accelerates ions up to 3.5 MeV/u, the second part provides for continuous variation of energies up to 7.3 MeV/u demanding by the experiments.

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DEMONSTRATOR ENVIRONMENT AT GSI

The cw demonstrator project [3] (started in 2010) is aiming to show the capability of sc 15 gap CH cavities to accelerate ion beams. The schematic view of the testing environment is shown in Fig. 2.

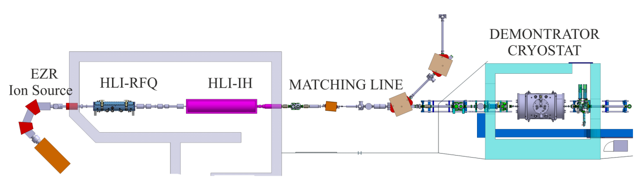

Figure 2: Testing environment for the demonstrator project at GSI.

The beam line before and behind the demonstrator cryostat is equipped with various beam diagnostic devices. Beam current transformers, Faraday cups, SEM-profile grids, a dedicated emittance meter [4], a bunch structure monitor [5] and phase probe pickups [6] (beam energy measurements applying time of flight) provides for proper beam characterization. At a beam time in 2015 the transverse emittance of Ar^{7+} and Ar^{10+} beams from HLI injector has been measured. These measurements [7] were used to calculate emittance backwards to the output of IH-DTL. The results are validated by comparison of measured emittance for various excitation of quadrupoles with calculated ones.

The liquid He cryostat maintains the cavity and two sc solenoids [3, 8] is placed within the radiation protection shelter. The cryostat is connected by flexible transfer line to liquid Helium reservoir with a capacity of 3000 liters, sufficient for one week of test operation. The used helium is collected by a 25 m^3 recovery balloon and then bottled by a compressor. The demands of the demonstrator project on liquid Helium is covered by an in house liquefier.

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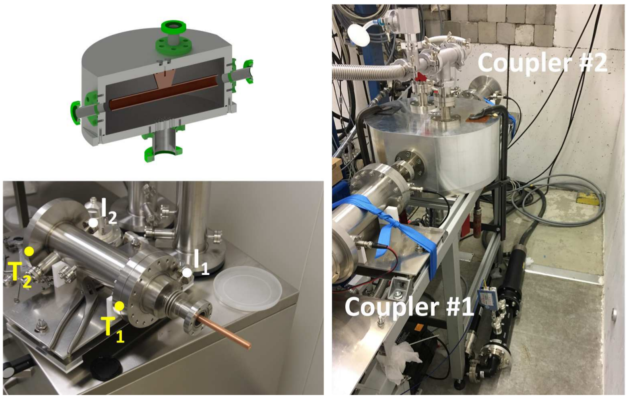

Figure 3: Testing bench for the rf power coupler at GSI.

All three accelerator components are suspended by eight tie rods, each mounted on a common support frame [9]. The support frame is suspended also by eight tie rods in a cross-like configuration balancing the mechanical stress during the cool down and warm up. The beam focusing solenoids provide maximum fields of 9.3 T with free beam aperture is 30 mm. A configuration of the main coil (Nb_3Sn) and two compensation coils (Nb_3Sn) compensates the maximum magnetic field of 9.3 T within a longitudinal distance of 10 cm down to 30 mT. The solenoids are connected to liquid He pots inside the cryostat by copper tapes allowing dry cooling. The cryostat and the solenoids were commissioned at the delivery in (December 2015). Measured standby losses of the cryostat are 4 W, it increase up to 8 W during ramping of solenoids with 5 A/s up to the nominal current of 110 A. The focusing properties of solenoids are tested during the beam time in July 2016 with Ar^{9+} beam. Besides the expected focusing a steering effects of up to 15 mm in vertical plane for both solenoids were detected at an excitation current of 40 A. This steering effects are not an obstacle for the testing of the demonstrator cavity with a beam. It is planned to equip the entire cw-linac with solenoids containing additional steering coils pair as for other projects [10, 11].

The sc 15 gap CH cavity is directly cooled with liquid Helium, supported by a Helium jacket out of titanium. The vendor RI (Research Instruments GmbH, Germany) provided for sufficient cavity preparation. After high pressure rinsing (HPR) a performance test in a vertical cryostat at low RF power was performed at IAP [12]. Three frequency tuners, developed at IAP [13] are manufactured at GSI for the control of resonance frequency. After the final assembly of the helium vessel and further HPR preparation at RI, the cavity was tested again in a horizontal cryo module. The cavity showed improved performance due to anew HPR treatment, the initial design quality factor Q_0 has been exceeded by a factor of 4, a maximum accelerating gradient of $E_{acc} = 9.6\,\mathrm{MV/m}$ at $Q_0 = 8.14 \cdot 10^8$ has been achieved [14]. Prior beam commissioning of demonstrator cavity, the rf power coupler [15] were tested and conditioned with dedicated test resonator [16] depicted on Fig. 3.

The couplers are equipped with sensors to control the temperature of the ceramic windows and Langmuir probes to detect multipacting current. A first conditioning [17] was done with pulsed RF (up to 5 kW) and later on in cw mode up to 2 kW. Further increase of the forward cw RF power leads to a temperatures rise more then 80 °C and could potentially damage the coupler. During the operation the "cold" window of coupler is anchored to the liquid Nitrogen supply tube by copper ribbons.

In a clean room of class ISO4 the power couplers were integrated in CH cavity, furthermore both solenoids and a cavity are assembled on a string and after leak testing the accelerating string was integrated [18] into a cryostat outside of clean room.

Recently (June, 28, 2017) the CH cavity accelerated first time heavy ion beams with full transmission up to the design beam energy of 1.85 MeV/u. For the first beam test the superconducting cavity was powered with 10 Watt of net RF power providing an accelerating voltage of more than 1.6 MV inside a length of 69 cm. Meanwhile the design acceleration gain of 0.5 MV has been verified with heavy ion beam of A/q = 6.7. A maximum average beam intensity of 1.5 pμA has been achieved, limited only by the pulse intensity of the injector and its maximum duty factor (25%), while the CH cavity was operated in cw-mode. The measured parameter of the heavy ion beam, delivered by ECR and HLI, show a nice beam quality: Transversal beam emittance as well as bunch structure has been measured for accelerated beam. The transversal beam emittance growth (90%, total) is less than 15%; a minimum bunch length of about 300 ps (FHWM) could be detected. The nominal accelerating gradient is achieved at 1.3 kW forwards RF power and leads to an increase of coupler window temperature from 180 K in standby up to 240 K. Further and more detailed tests and careful evaluation of data are envisaged [19].

LAYOUT OF STANDATD CRYOMODULE FOR ADWANCED DEMONSTRATOR

The successor of the demonstrator R&D is the Advanced Demonstrator (AD) project. It is planned to build the first quarter of the entire cw Linac. Based on beam dynamics calculations [20,21], a standard cw-Linac cryo module, comprising three CH cavities, a sc rebuncher CH cavity and two solenoids, was newly defined and depicten on the Fig.4.

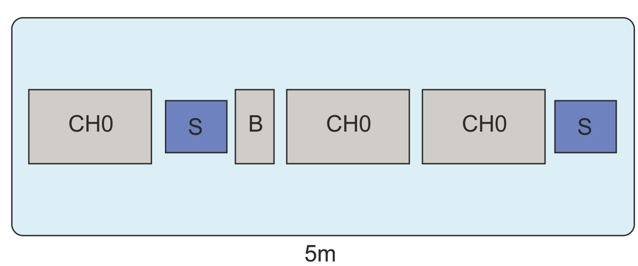

Figure 4: Layout of the first of four cryomodules for cw linac.

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While the demon-strator cavity will serve as the first accelerating cavity for the AD, two short CH-cavities [22] are under construction at RI, complementing the first cryomodule (CM1). Besides CM1, the revised design of the sc cw-Linac comprises three additional cryo modules (CM2-CM4) each equipped with three short CH-cavities. The short cavity has a design gradient of 5 MV/m as well.

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