ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME004

FURTHER R&D FOR A NEW SUPERCONDUCTING CW HEAVY ION LINAC@GSI

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Abstract

A low energy beam line (1.4 MeV/u) behind the GSI High Charge State Injector (HLI) will provide cw-heavy ion beams with high beam intensity. It is foreseen to build a new cw-heavy ion LINAC for post acceleration up to 7.3 MeV/u. In preparation an advanced R&D program is defined: The first LINAC section (financed by HIM and partly by HGF-ARD-initiative) comprising a sc CH-cavity embedded by two sc solenoids will be tested in 2014/15 as a demonstrator. After successful testing the construction of an advanced cryo module comprising four CH cavities is foreseen. As an intermediate step towards an entire cw-LINAC the use of a double of two CH-cavities is planned: A short 5 cell cavity should be mounted directly behind the demonstrator cavity inside a short cryostat. The design of the cw LINAC based on shorter sc CH-cavities would minimize the overall technical risk and costs. Besides with this cavity an optimized operation of the whole LINAC especially with respect to beam quality could be achieved. Last but not least the concept of continuous energy variation applying phase variation between the two cavities with constant beta profile could be tested.

INTRODUCTION

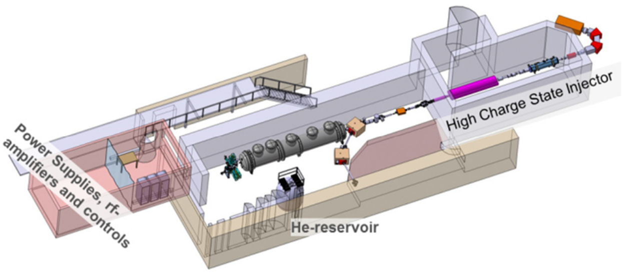

Figure 1: CH-multi cavity test environment@GSI.

Providing heavy ion beams for the ambitious experiment program at GSI, the Universal Linear Accelerator (UNILAC) combined with the High Charge State Injector (HLI) served at last as a powerful high duty factor (25%) accelerator. An UNILAC upgrade program is starting soon, designated to prepare for high intensity high current synchrotron injector operation for FAIR (Facility for Antiproton and Ion Research). As a result beam time availability for SHE-research will be strongly diminished due to the duty factor limitation for the UNILAC FAIR injector operation. To keep the SHE program at GSI competitive [1], an upgrade program of the HLI was already initialized comprising a new 28 GHz ECR source and a cw capable RFQ and an IH-DTL [2]. A standalone sc cw-LINAC [3] in combination with the upgraded HLI is assumed to meet the demands of the experimental program at its best. With significant higher beam intensity the SHE production rate will be increased as well.

A conceptual layout [3] of a sc cw-LINAC was worked out, which allows the acceleration of highly charged ions with a mass to charge ratio of 6 at 1.4 MeV/u from the upgraded HLI. Nine superconducting CH-cavities operated at 217 MHz accelerate the ions to energies between 3.5 MeV/u and 7.3 MeV/u, while the energy spread should be kept smaller than ±3keV/u. Superconducting solenoids mounted between the cavities provide for proper beam focusing. The general parameters are listed in Table 1.

Table 1: Design Parameters of the Cw-LINAC

Mass/Charge		6
Frequency	MHz	217
Max. beam current	mA	1
Injection Energy	AMeV	1.4
Output energy	AMeV	3.5 – 7.3
Output energy spread	AMeV	±3
Length of acceleration	m	12.7
Sc CH-cavities		9
Sc solenoids		7

R&D and prototyping (demonstrator project) [4,5] in preparation of the proposed cw-LINAC is assigned to a collaboration of GSI, IAP and HIM, which was founded in 2009. The selected location to setup the Demonstrator is in straightforward direction of the HLI at GSI (Fig. 1). Two existing experiments at the HLI had to move since the space is needed for the demonstrator test environment embedded in a new radiation protection cave. The liquid helium (LHe) supply is covered by a 3000 ltr. tank. The consumed helium is collected in a 25 m^3 recovery balloon and bottled by a compressor. For matching the beam from the HLI to the demonstrator a new rebuncher cavity as well as an existing rebuncher and an additional quadrupole doublet will be used. Moreover beam diagnostic devices, like SEM-profile grids and an emittance measurement devices and phase probes for beam energy measurements applying time of flight (TOF) has to be integrated in the beam line in front of and behind the demonstrator as well.

CH-CAVITIES

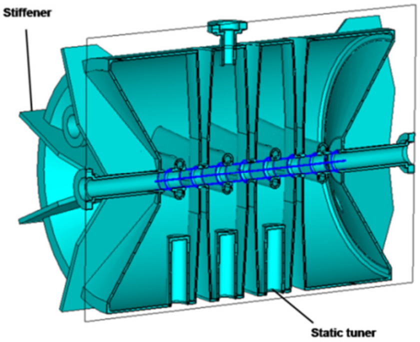

Figure 2: Geometry of the "short" 217 MHz CH-cavity.

Generally superconducting CH-cavities are very similar to the well-known multi spoke cavities. Additionally CH-cavities may potentially be equipped with an internal velocity profile. Recently several superconducting CH-cavities have been developed at IAP [6,7]: A first 19-cell prototype cavity has reached effective gradients of 7 MV/m and a Q_0-values between 10^8 and 10^9 (effective voltage of 5.5 MV). Another CH-cavity, a 325 MHz 7-cell cavity, could be operated at 2.2 MV/m, while surface preparation as BCP and HPR was not applied. After the surface treatment the high power cavity tests was repeated, resulting in sufficiently high quality factor (9×10^8) and accelerating gradient (7.7 MV/m). A third cavity (217 MHz, 15 cells) [8], serving for the first demonstrator assembly, is presently under fabrication. As a next step of cavity investigation, a "short" superconducting 8-gap CH-cavity [9], operated at 217 MHz as well, has been designed by IAP (Fig. 2). Different design objectives will be pursued for this advanced cavity. The first CH-cavitiy releases have so called girders in which the stems are welded. This processing step lead to high fabrication costs and extended fabrication duration. Additionally the girders reduce the mechanical stability of the cavity caused by a break of the cylindrical symmetry. Furthermore it is intended to investigate the influence of BCP to the cavity frequency: Two BCP treat-ments of at least 100 µm each are planned for comparison with simulation and analytical approaches. Finally the cavity frequency tuning has to be accomplished.

The CH-cavity has a resonance frequency of 217 MHz, it will accelerate heavy ions up to a synchronous velocity of $\beta = 0.069$. The corresponding cell length $\beta\lambda/2$ is 47.7 mm. Following the EQUUS [3] beam dynamics concept the cells length is kept constant along the profile. Achievement of the desired resonance frequency after BCP and after evacuation@4K is a special concern. Especially the shrinking due to electron beam welding has to be considered accurately. However, the right frequency within the cavity bandwidth is only reachable taking further action into account. A tuning concept dedicated to CH-cavity operation structures is investigated and has been validated theoretically and experimentally. Several static tuners are foreseen for coarse tuning during fabrication process. These tuners (bulk niobium) are cylindrical bodies acting capacitively to the high electric field region. It is essential to follow carefully an elaborated scheme of tuning and surface preparation. Additionally an evacuation test ($p_{min}=1\cdot10^{-4}$ mbar) and a cold test at T=77 K is foreseen before welding of the last tuner.

The two coaxial power coupler couplers are located between two stems. To provide enough coupling strength the tip of the power coupler is relatively close to the stem center; additional heating of the inner conductor (due to rf-magnetic field from cavity) is avoided by additional shielding made out of niobium which acts as prolongation of the outer conductor [10].

Table 2: Main Parameters of "short" 217MHz CH-cavity

Frequency	217	MHz
β	0.069	
Length ($8\beta\lambda/2$)	381.6	mm
Number gaps	8	
Inner tank diameter	438	mm
Aperture diameter	30	mm
Maximum inner length	560	mm
Wall thickness	≈3.5-4	mm
E_p/E_a	5.3	
B_p/E_a	6.5	mT/(MV/m)
E_a	>5	MV/m

DEMONSTRATOR PROJECT

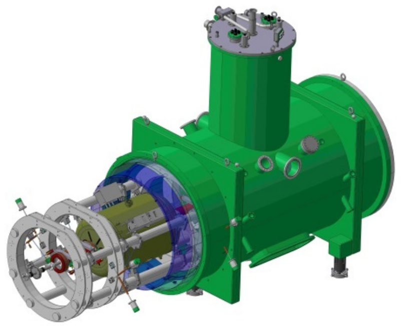

Figure 3: Cryostat with CH-cavity, high field solenoids, cold warm transitions and support system (Cryogenic).

The demonstrator (see Fig. 3) [11] is a prototype of the first section of the proposed cw-LINAC, comprising a superconducting CH-cavity embedded by two superconducting solenoids. A study was conducted, which showed an assembly concept for the cryostat comprising the solenoids and the cavity as well. It is intended to align the three components to the beam axis. The sc CH-structure is the key component and offers a variety of

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research and development. The beam focussing solenoids provide maximum fields of 9.3 T at an overall length of 380 mm and a free beam aperture of 30 mm. The magnetic induction of the fringe is minimized to 50 mT at the inner NbTi-surface of the neighbouring cavity. Based on the 9 T solenoid design for the ISAC-II cryo module a coil configuration with two main coils and two bucking coils was assumed to meet the demands at best. Design gradients can be achieved by using anti-windings.

MULTI CAVITY MODULES

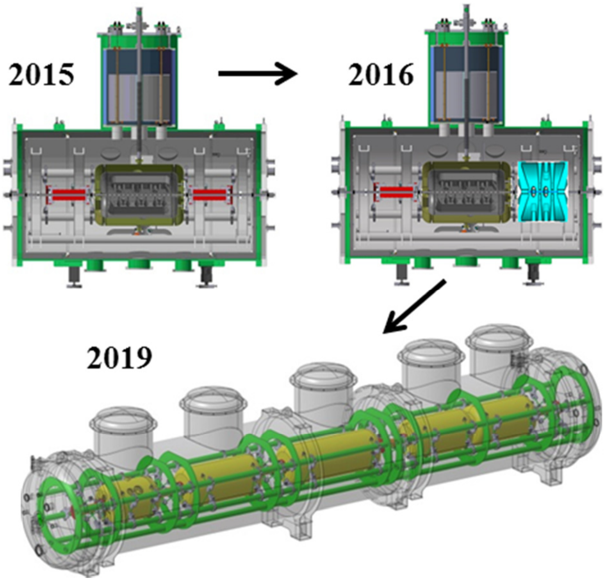

Figure 4: Single 15 cell cavity module (top, left) embedded in the cryo environment, additional 8 cell cavity substituting solenoid 2 (top, right) and draft layout of a multi cavity advanced demonstrator (bottom).

Design constrains: The cell length in each individual cavity is constant but changes from cavity to cavity. The RF phase changes from gap to gap. To minimize the number of cavities the phase slip for stable longitudinal motion has been maximized, leading to a large number of accelerating cells, while the sensitivity for field and frequency deviations is increased. Additionally beam quality suffers, if all beam energies between 3.5 MeV/u and 7.3 MeV/u have to be provided. Avoiding these issues it could be more advantageous to use “short” cavities with lower number of accelerating cells. Two short cavities placed in one cryo modules simplify assembly, potentially warm quadruplets in between could provide for transverse beam focusing. Additional beam diagnostics could be mounted in the warm sections.

As the next technological step it is intended to integrate the “short” cavity in the demonstrator cryo module even together with the cavity which is already under fabrication. A beam test with a CH-cavity double is another milestone towards an entire CH cavity string (advanced demonstrator). Mainly the concept of beam continuous energy variation applying phase variation between the two cavities could be tested. The design, construction and operation of the new cavity would be another important step. Inside the multi stage approach of cw-LINAC R&D, construction and successful testing of an advanced cryo module (Fig. 4) is the final milestone. The design of this advanced demonstrator unit [12] should be based on the layout of the single cavity module (demonstrator) and/or double cavity module (CH double). A first basic layout is shown in Fig. 5: The beam from the HLI (1.4 MeV/u) is matched to the demonstrator and further accelerate to 6 MeV/u in an array of 5 cryostats each comprising a doubles of short sc CH cavities.

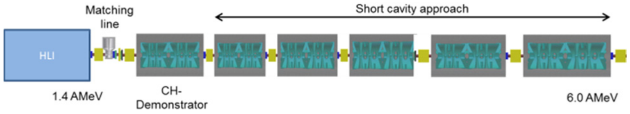

Figure 5: Advanced demonstrator layout based on short cavity approach; (warm) magnetic quadruplet focusing.

CONCLUSION

The design of the cw LINAC based on shorter sc CH-cavities could minimize the overall technical risk and costs. Applying short CH-cavities an optimized operation of the whole LINAC with respect to beam quality could be achieved. A multi stage approach of R&D is envisaged for fixing an optimized heavy ion cw-LINAC design.

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