ADVANCED SUPERCONDUCTING CW HEAVY ION LINAC R&D *

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Abstract

An advanced upgrade program has to be realized in the next years, in order to provide enhanced primary beam intensities. Therefore a new sc 28 GHz full performance ECR ion source has to be established. Via a new low energy beam line an already installed new RFQ and an IH-DTL will provide cw-heavy ion beams with high average beam intensity. It is foreseen to build a new cw-heavy ion-linac [1] behind this high charge state injector. 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 as a demonstrator. After successful testing the construction of an advanced cryomodule comprising four rf cavities is foreseen. A first layout of this advanced test bench will be presented.

INTRODUCTION

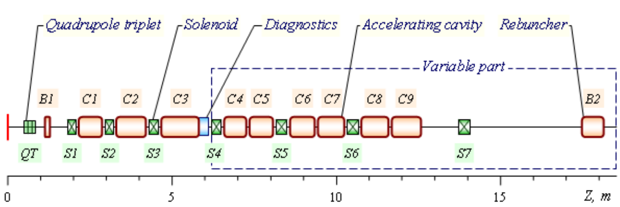

Figure 1: Draft layout of the future GSI cw-LINAC in parallel to the existing UNILAC (Ci = Cavity, Bi = (Re) Buncher, Si = Solenoid, QT = Quadrupole-Triplet).

Providing heavy ion beams for the ambitious experiment program at GSI, the Universal Linear Accelerator (UNILAC) combined with the High Charge State Injector (HLI) serves as a powerful high duty factor (25%) accelerator. In the next future the UNILAC is designated as a high intensity high current synchrotron injector for FAIR (Facility for Antiproton and Ion Research). Beam time availability for SHE-research will be decreased due to the limitation of the UNILAC providing a proper beam for SHE and fulfilling the requirements for FAIR simultaneously. To keep the SHE program at GSI competitive on a high level, an upgrade program of the HLI was initialized comprising a new 28 GHz ECR source and a new cw capable RFQ [2,3]. As a result of a long term cost to performance benefit analysis a standalone sc cw-LINAC in combination with the upgraded HLI is assumed to meet the demands of the experimental program at its best [4]. Significant higher beam intensities will be provided and lead to an increase of the SHE production rate.

GENERAL CW-LINAC DESIGN

The technical design of such a sc cw-LINAC is assigned to a collaboration of GSI, IAP and HIM, which was founded in 2009. A conceptual layout [1,5] (see fig. 1) 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 AMeV from the upgraded HLI. Nine superconducting CH-cavities [6] operated at 217 MHz accelerate the ions to energies between 3.5 AMeV and 7.3 AMeV, while the energy spread should be kept smaller than ±3keV/u. Seven superconducting solenoids are applied as beam focusing elements. 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

DEMONSTRATOR PROJECT

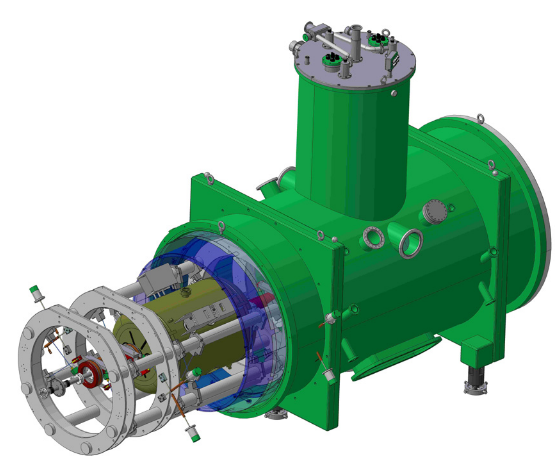

Figure 2: Cryostat with CH-cavity, high field solenoids, cold warm transitions and support system (Cryogenic).

The demonstrator is a prototype of the first section of the proposed cw-LINAC, comprising a superconducting CH-cavity [5,6,7] embedded by two superconducting solenoids. A study is conducted providing a concept to assemble the cryostat with the solenoids and the cavity as well as to align the three components to the beam axis [8]. The sc CH-structure is the key component and offers a variety of research and development. A first prototype of a 360 MHz sc CH-cavity (β=0.16, 19 gaps) was tested at the IAP successfully. In vertical rf-tests maximum gradients of up to 7 MV/m at Q_0-values between 10^8 and 10^9 were achieved. The fabrication of another 325 MHz sc CH-cavity (β = 0.16, 7gaps) is expected for delivery. The cavities designed for the cw-LINAC are operated at 217 MHz and should provide gradients of 5.1 MV/m at a total length of minimum 0.69 m. 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 cryomodule 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 [9].

MULTI CAVITY MODULE

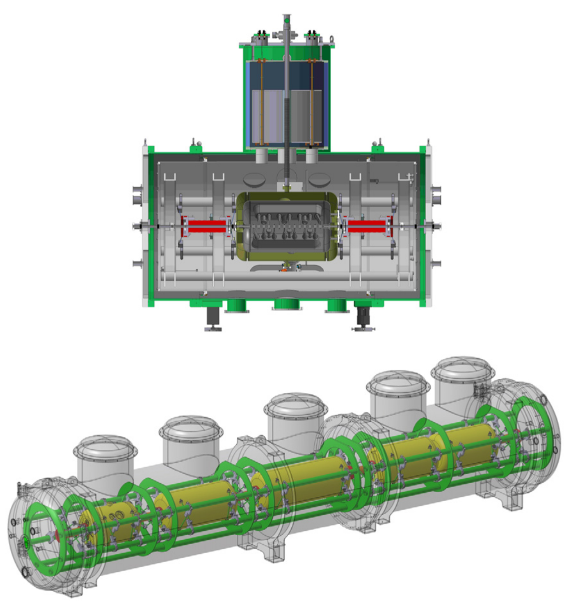

Figure 3: Single 15 cell cavity module (top) embedded in the cryo environment (Cryogenic); draft version of a multi cavity advanced demonstrator layout (bottom).

As the next technological step the construction of an advanced cryomodule (fig. 3) is proposed. The design of this accelerator unit is based on the layout of the single cavity module (demonstrator) to be built and tested in the next future. As shown in fig. 3 this base unit comprises a CH cavity as a key component and a high field solenoid in front and another one behind the cavity [9,10,11]. It is planned to extend for another 4 cavities as well as 3 additional solenoids.

Table 2: Design Parameters (advanced demonstrator) [1]

Parameter	*unit*	*C1*	*C2*	*C3*	*C4*	*C5*
Gap number		15	17	19	10	10
Total length	mm	613	811	1054	636	642
Cell length,	mm	40.8	47.7	55.5	63.6	64.2
Synch. velocity		0.059	0.069	0.080	0.092	0.093
Aperture diameter	mm	20	22	24	26	28
Eff. Gap voltage	kV	225	274	317	356	362
Voltage gain	MV	3.13	4.14	5.42	3.27	3.30
Phase Factor		0.93	0.89	0.90	0.92	0.91
Accelerating rate	MV/m	5.1	5.1	5.1	5.1	5.1

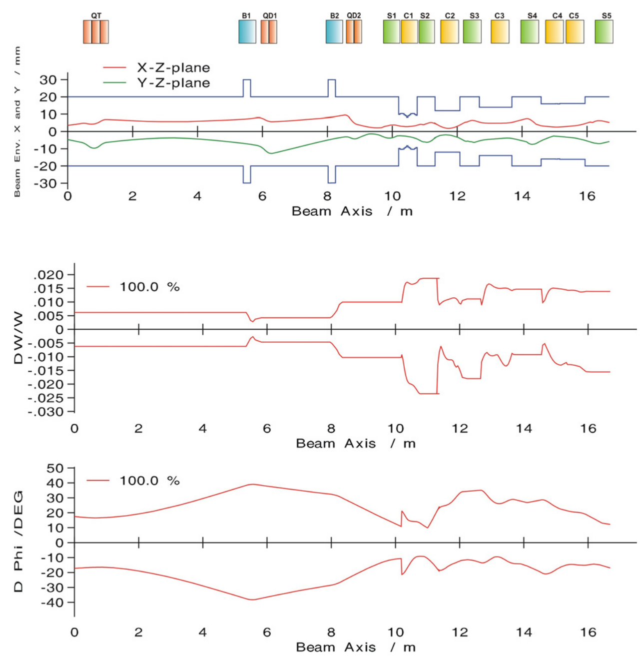

Figure 4: Preliminary beam dynamics layout of the advanced demonstrator; transverse (above) and longitudinal (beneath) envelopes for matching line and complete advanced demonstrator approach (4.61 MeV/u, max. beam energy).

Beam dynamics for the advanced demonstrator has been simulated with the LORASR code. A particle array calculated at the output of the existing IH - HLI has been used as an input for these simulations. Since the expected current of heavy ions will certainly not exceed 1mA, space charge effects are supposed to be negligible. A preliminary calculated beam dynamics layout behind the HLI at 1.4 AMeV is shown in Fig.4. The room temperature focusing quadrupoles (triplet and 2 duplets) provides enough space for 2 rebuncher cavities, input beam diagnostics and cold-warm junction of the cryostat. At the same time, it makes the input beam axially symmetric for further solenoid focusing due to especially chosen gradients. The beam is matched to the

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demonstrator in the 6d phase space. The first part of the linac up to the energy of 3.5 AMeV includes three constant cell superconducting cavities with 15, 17 and 19 cells, respectively, and three superconducting solenoids. Minimum RF phases of the bunch center at these sections are -45°, -55°, -55°, respectively, being realized at the first and last cells of each section while the maximum acceleration occurs in the middle. Note that the average phase values for the first three sections are as large as -19°, -22° and -28°, which is smaller than the typical value of -30°, used for traditional structures, but the longitudinal bunch stability is maintained due to the additional alternating effect. Moreover, periodic over-bunching at the ends of the sections fits well to the structure with the long focusing period and separated lenses.

Table 3: Design Parameters of Superconducting Solenoids

Parameter	***unit***	***S1***	***S2***	***S3***	***S4***	***S5***
Effective length	mm	250	250	300	300	350
Magnetic induction	T	8.15	9.5	9.1	9.15	9.6
Aperture diameter	mm	30	30	≥30	≥30	≥30

The energy variable section comprises two focusing solenoids and two 10-gap, constant cell - cavities. In principle, beam dynamics would allow long single accelerating sections with 20 gaps and more between solenoids, but two separated superconducting cavities have been chosen for the reasons of cavity production and stability. In order to keep the efficient phase profile, used at the initial part of the linac, the bunch center starts from the negative phase, namely -50° at the beginning of the first section and moves to zero phase. Along the second cavity the bunch center slides back to the negative phase, coming then to the final solenoid. The basic parameters of the solenoid channel are summarized in tab. 3. A final debunching section is not considered until now. After a drift a final 108 MHz buncher could generally minimize the energy spread to the desired value.

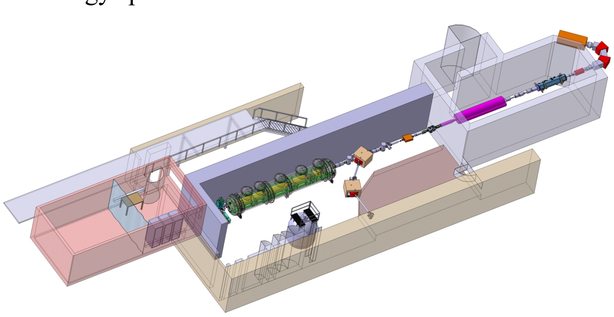

Figure 5: Advanced demonstrator to be mounted in the GSI-HLI hall. Radiation shielding, cryo infrastructure and a local control room are already considered.

TIME TABLE [12]

A preliminary time schedule for the complete cw-linac-R&D is shown in tab 4. The delivery of all demonstrator components is foreseen until end of 2013; rf-testing and a full performance test are scheduled for 2014. The kick off for the advanced demonstrator R&D project depends on successful testing of the basic demonstrator module; the earliest time for commissioning is 2018.

Table 4: Time Schedule

	Multi cavity Demonstrator-Project
≤2011	tendering for the cryostat and the solenoids
	ordering the cavity, the rf- amplifier and the LHE- supply
end of 2011	delivery of the rf- amplifier and the Lhe- supply
	tendering procedure for the cryostat and solenoids
2012	ordering cryostat and solenoids
	preparing the infrastructure and the Demonstrator shielding cave
	emittance measuremts of the HLI- beam/matching the Demonstrator
2013	construction of the Demonstrator infrastructure completed
	delivery of the 217MHz Cavity (SAT, FAT)
End 2013	delivery of the cryostat and solenoids
	assembly of the complete demonstrator; cold warm testing
2014	full performance test@GSI
2018	Commissioning Advanced Demonstrator (multi cavity)

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