ADVANCED LAYOUT STUDIES FOR THE GSI CW-LINAC

W. Barth[1,2], S. Jacke[2], S. Mickat[1,2]
[1]GSI Helmholtzzentrum, 64291 Darmstadt, Germany
[2]Helmholtz-Institut Mainz (HIM), 55099 Mainz, Germany

Abstract

Beam dynamics studies were made with the LORASR code for the planned superconducting (sc)-continuous wave (cw)- linear accelerator. It comprises a fixed accelerating part with output energy of 3.5 MeV/u at a design mass/charge ratio of 6 and an energy variable part with output energy of up to 7.3 MeV/u. The general layout comprises nine cavities, combined with seven separate solenoids at a total length of 12.7 m. It is based on a conceptual design of S. Minaev [1]. Recently a parameter study for output energy variation was performed. The statistical rotational and transverse offset error calculations illuminate the tolerances for acceptable alignment errors. These are particularly relevant in the beam dynamics within a superconducting environment. Further calculations focus on varying the charge to mass ratio to reach linac energies up to 10 MeV/u, meeting the requirements of future UNILAC experiments.

INTRODUCTION

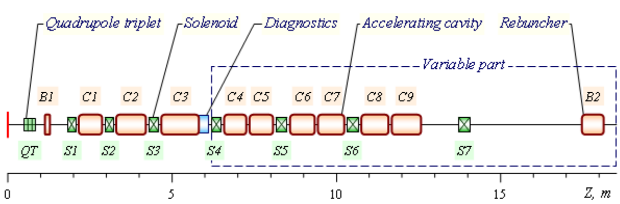

Figure 1: Draft layout of the future GSI cw-LINAC in parallel to the existing UNILAC (Ci = Cavity, Bi = (Re) Buncher, Si = Solenoid, QT = Quadrupole-Triplet).

Since 1981 six new elements, from element 107 to element 112, were discovered at GSI. The GSI-HLI in combination with the Universal Linear Accelerator (UNILAC) is not dedicated to fulfil the SHE-requirements. In the next future the UNILAC is designated as an 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 in providing high intensity heavy ion beams for the FAIR-synchrotron. To keep the SHE program at GSI competitive on a high level, an upgrade program of the HLI was initialized comprising a new sc 28 GHz ECR source and a new cw capable RFQ [2,3]. As a result of a long term cost-benefit analysis a standalone sc cw-LINAC in combination with the upgraded HLI is assumed to fit the requirements of SHE at best [4]. Significant higher beam intensities will be provided and lead to an increase of the SHE production rate. The technical design and the realisation of such a sc cw-LINAC in parallel to the existing UNILAC at GSI is assigned to a collaboration of GSI, the Institute of Applied physics of the Goethe University Frankfurt (IAP), and the Helmholtz-Institute Mainz (HIM), which was founded in 2009.

A conceptual layout of a sc cw-LINAC was worked out [1], 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 (Fig. 1). Nine superconducting CH-cavities operated at 217 MHz accelerate the ions to energies between 3.5 MeV/u and 7.5 MeV/u, while the energy spread should be kept smaller than ±3keV/u. As beam focusing elements seven superconducting solenoids are applied. General parameters are listed in table 1. The commissioning of the cw-LINAC is scheduled for 2018 at earliest. Proposals for the financing of the project were submitted in 2009 and 2011, both were evaluated excellent by the Helmholtz Gemeinschaft Deutscher Forschungszentren (HGF). Presently prototyping is on the way to start a full performance beam test at GSI. Beam dynamics investigations are performed to fit the cw-LINAC design to the technical and on-site conditions as well as to the requirements of the future user community.

Table 1: Design Parameters of the cw-LINAC

Mass/Charge		6
Frequency	MHz	217
Max. beam current	mA	1
Injection Energy	MeV/u	1.4
Output energy	MeV/u	3.5 – 7.5
Output energy spread	keV/u	+- 3
Length of acceleration	m	12.7
Sc CH-cavities		9
Sc solenoids		7

CW-LINAC DEMONSTRATOR

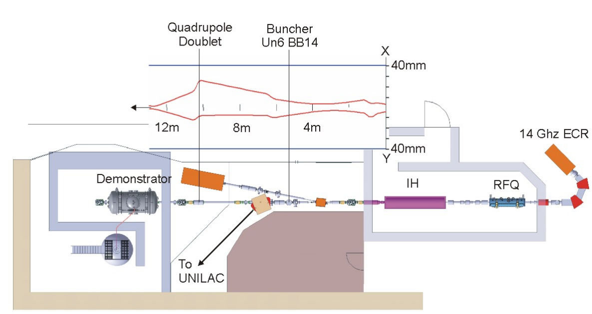

Figure 2: cw-linac-demonstrator set up@GSI-HLI.

ISBN 978-3-95450-115-1

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 has been worked out which provided 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 currently in progress. 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 effective length of 290 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 [9] a coil configuration with two main coils and two bucking coils was assumed to fit the requirements at best. Design gradients can be achieved by using anti-windings [10].

The favoured location to setup the Demonstrator is in straightforward direction of the HLI at GSI (Fig. 2). Two existing experiments at the HLI have 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. In operation a consumption of 20 ltr LHe per hour is predicted.

For matching the beam from the HLI to the demonstrator an existing rebuncher cavity can be used, as well as an additional quadrupole doublet. 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.

BEAM DYNAMICS STUDIES

Beam dynamic studies were performed to investigate the recent conceptual design of the linac, and to prepare the technical design as a next step on the way for a complete linac layout. Before the detailed rf-layout of each multicell CH cavities will start, it were intended to check the tolerances for acceptable alignment errors of the main linac components as rf-cavities and all focussing solenoids. These are particularly relevant in the beam dynamics within a superconducting environment. Further calculations focus on varying the charge to mass ratio to reach linac energies up to 10 MeV/u, meeting the requirements of future UNILAC experiments.

Error Studies

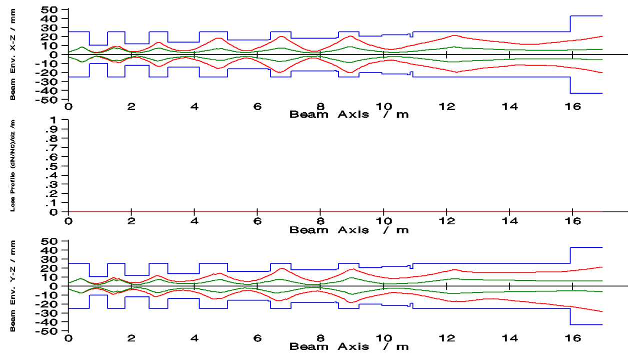

Figure 3: LORASR-error studies assuming statistical errors for positioning and rotation of beam line components.

The influences of statistical errors were investigated on the basis of 300 LORASR-simulation runs. A statistical distribution of horizontal and vertical shift of beam line components of ±300 µm was assumed as well as a statistical tilt error of ±1.7 mrad. Fig. 3 shows the design transversal beam envelopes (green) and the maximum beam envelope considering the 300 simulation runs in total (red); no transmission loss was observed confirming a robust beam dynamical layout of the linac.

Beam Energy Variation

Table 2: Summary of Beam Energy Variation Studies (mass/charge = 6)

final beam energy [MeV]	rf-phase [°]		eff. gap voltage [MV]					
	Cav. 8	Cav. 9	Cav. 5	Cav. 6	Cav. 7	Cav. 8	Cav. 9	4 gap-Deb.
27.0 - 27.4	-56	-69	0.19	0.11	0.17	0.00	0.41-0.31	1.37
30.2	-86	-99	Design	0.33	0.01	0.01	0.00	1.37
36.0 - 31.7	-86	-99	Design	0.51-0.00	Design	0.41	0.01	-0.15 - 1.37
36.0 - 37.8	-86	-99	Design	Design	Design	0.34	0.00	0.00 - 0.15
37.8 - 42.0	-86	-99	Design	Design	Design	0.36	0.00-0.23	0.15

Coarse energy variation is provided by switching off the cavities one after another, starting from the end of the LINAC, as it is practiced successfully at the GSI-UNILAC. The transverse focussing has to be corrected to keep the transverse beam envelope small. According to the beam requirements, the energy spread shall not exceed +-3 MeV/u over the whole range of energy variation. To fulfil this condition, the last section has to operate as an additional rebuncher with an rf phase of +90° in the bunch centre. The rf voltage applied to this section has to be properly chosen depending on the number of operating cavities, keeping the bunch length at the final rebuncher in the range of 90°-120°. Beam dynamics for different cases have been simulated by using the LORASR code. Calculations show that the final 10-gap equidistant section efficiently operates as a rebuncher even for the minimum energy of 3.5 AMeV. The desired result has

been achieved by matched rf voltages of the last section, which were always lower than the nominal value for full energy operation. The energy spread, calculated for different beam energies meets the design requirement of ±3 AkeV.
Smooth energy variation is achieved by changing the rf voltage applied to the last operating section. Tab. 2 summarizes the calculated beam energy as a function of different gap voltages of cavity 5, 6, 7, 8 and 9 and different rf-phase for the last two tanks. The voltage-energy dependence is not exactly linear, but allows for easy beam energy variation. Alternatively smooth energy variation is accomplished by varying the rf phase and has to be investigated in more detail. Energy variation by changing the rf-phase may help to avoid multipacting effects at lower rf-voltages.

The last two cavities can be switched off without loosing particles and beam brilliance; the beam energy is reduced accordingly. If one of the cavity 5 to 7 may fail during operation no particle losses are predicted, while the maximum beam energy for the design ion is reduced: 5.3 - 6.5 AMeV.

LINAC-Booster Operation

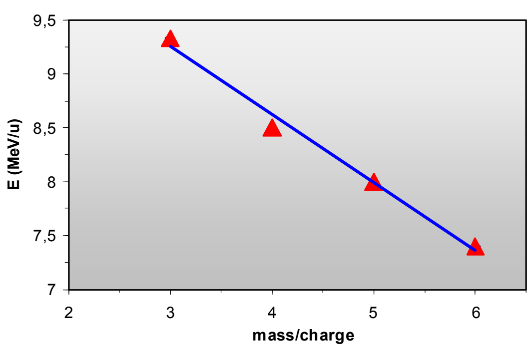

Figure 4: Maximum linac beam energy as function of the mass to charge ratio of the accelerated heavy ion beam applying the design gap voltage.

Several physics experiments requests for beam energies above the linac design (7.5 MeV/u). Accelerators with a fixed Beta-profile are not able to provide for this. With the dedicated beam dynamics design (EQUUS) the linac beam energy for heavy ion beams with a lower rigidity could be boost up to 10 MeV/u, as shown in Fig. 4. For instance ion beams from the High Current Injector of the UNILAC could be transferred to the cw-linac. Making use of the installed 1.4 MeV/u-stripper and the adjacent charge state separator system, highly charged ion beams with a high duty factor could be accelerated up to 15% speed of light.

TIME SCHEDULE

A preliminary time schedule is shown in table 3. Delivery of all demonstrator components is foreseen until 2013; rf-testing and full performance test is scheduled for 2013/14. The kick off for linac project depends on a successful R&D; the earliest time for linac commissioning is 2018.

Table 3: Time Schedule [11, 12]

	cw-LINAC – and 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
Mid 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 earliest	Commissioning „sc cw LINAC“

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