A cw OPERATED SUPERCONDUCTING HEAVY ION LINAC FOR SUPER HEAVY ELEMENT RESEARCH AT GSI*

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Abstract

The search for Super-Heavy Elements (SHE) is one of the frontiers in nuclear physics. By trend the production cross sections decrease significantly for larger proton numbers and heavier nuclei, respectively. To limit the required beam time it is necessary to use the highest available intensity. This prefers cw operation and the use of superconducting cavities. A cw operated superconducting linac using CH-cavities at GSI has been designed. As front end the existing 108 MHz High Charge Injector (HLI) will be used which is presently being upgraded for cw operation. The superconducting part of the linac covers the energy between 1.4 AMeV and 7.3 AMeV. It consists of 9 multicell CH-cavities operated at 217 MHz. Each cavity is optimized for a specific particle velocity but without beta profile. Above 3.5 AMeV the linac is fully energy variable. The first superconducting CH-cavity will be constructed tested with beam delivered by the HLI.

The development of the prototypes and the overall design including beam dynamics issues is presented.

INTRODUCTION

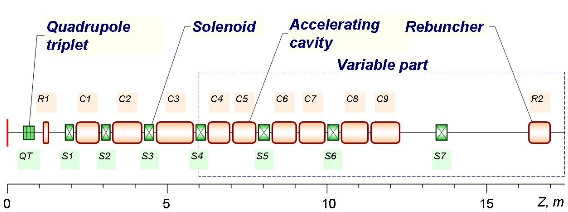

Figure 1: Schematic layout of the proposed cw linac for super heavy element research at GSI.

The proposed linac has to accelerate heavy ions to the Coulomb barrier. Above an energy of 3.5 AMeV the linac should be fully energy variable up to 7.3 AMeV. To increase the average beam intensity cw operation is required which makes superconducting operation preferable. As accelerating cavities superconducting CH-structures have been chosen [1]. These multi-cell cavities will give a large energy gain per cavity resulting in a very compact linac design. Measurements of a first superconducting CH-protoype cavity have shown accelerating gradients of 7 MV/m [2].

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The linac which will provide a total effective voltage of 35 MV. It consists of 9 CH-cavities within two cryo modules, superconducting solenoids will be used for transverse inter-tank focusing. A de-buncher cavity placed 6 m behind the last CH-cavitiy is used to minimise the energy spread for the experiments. Figure 1 shows the layout of the linac and figure 2 shows the overview of the GSI Unilac and the location of the new superconducting linac. Table 1 sumarrises the main parameters of the cw linac.

Table 1: General Parameters of the Superconducting Energy Variable Heavy Ion Linac

Parameter	**Value**
A/q	6
f	216.816 MHz
Beam current	1 mA
Injection energy	1.39 AMeV
$\epsilon_{in,tr}$, (norm.)	$0.8\ \pi\text{mm} \cdot \text{mrad}$
$\epsilon_{in,long}$, (norm.)	$1.9\ \text{AkeV} \cdot \text{ns}$
Output energy	$3.51 - 7.30$ AMeV
Output energy spread	± 3 AkeV
Transv. rms emit. growth	5 %
Long. rms emit. growth	6 %
Length of accelerating part	12.7 m
Number of sc cavities	9
Number of sc solenoids	7

EQUUS BEAM DYNAMICS

Generally the KONUS beam dynamics is used in H-mode drift tube cavities like IH- or CH-structures [3]. In case of this cw linac the so called **EQUUS** (**EQU**idistant m**U**ltigap **S**tructure) concept has been proposed [4]. Despite of the increasing velocity all accelerating cells within one specific cavity are kept constant. This leads to less complex cavities which are easier to fabricate und to tune.

The constant periodic cell length along each cavity is chosen correspondingly to the average particle velocity. At the entrance of each cavity the particles enter the first gap at negative phase. Initially they are slower than the travelling wave leading to a sliding of the bunch towards the crest of the wave. In the second half of the cavity the particles are faster and moving back to negative phases.

The maximum number of gaps depends in the EQUUS concept depends on the frequency, the charge-to-mass ratio (i.e. energy gain per nucleon) and on the accelerating gradient [4]. Figure 3 shows the RF phases of the bunch centers

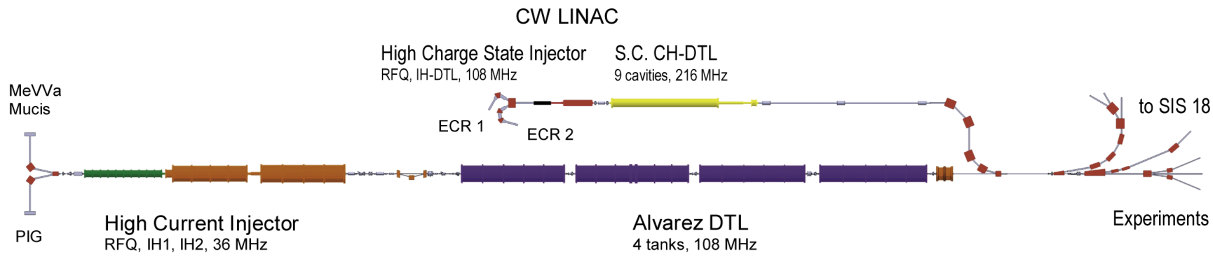

Figure 2: Overview of the GSI Unilac and the location of the new superconducting cw-linac.

in the middle of all accelerating gaps along the CH-cavities. In the first three CH-cavities the RF phase in the first and last gap is identical. In the energy variable part above an energy of 3.5 AMeV one "EQUUS"-period is splitted into two identical cavities to avoid too long cavities which could cause problems during fabrication.

Figure 4 shows the phase space projections at the entrance into the superconducting CH-linac and behind the de-buncher cavity. The emittance growth (without errors) is very small with around 5%. The simulated transmission is 100%.

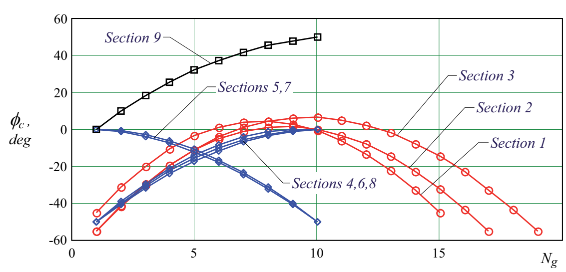

Figure 3: RF phases of the bunch centers in the center of all accelerating gaps along the CH-cavities

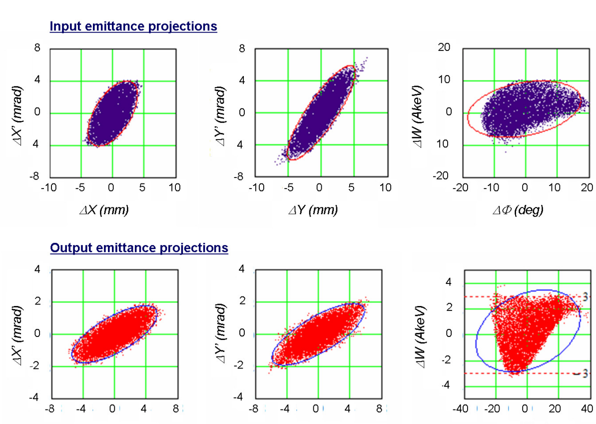

Figure 4: Phase space projections at the entrance of the superconducting CH-linac and behind the de-buncher.

PROTOTYPE DEVELOPMENT

Presently a superconducting 325 MHz CH-cavity is under fabrication. Compared with the first CH-prototype cavity the geometry has been further optimised. This cavity (Fig. 5) will be fully equipped with helium vessel, power couplers and a new tuning system. The recently developed tuner is a bellow tuner which acts capacitively. One slow tuner and one fast tuner based on piezo technology will be used. Four additional flanges are foreseen to simplify the surface preparation of the cavity. It is planned to test this cavity with beam at the 108.4 MHz GSI Unilac with a 11.4 AMeV beam. The 217 MHz cavities for the cw linac

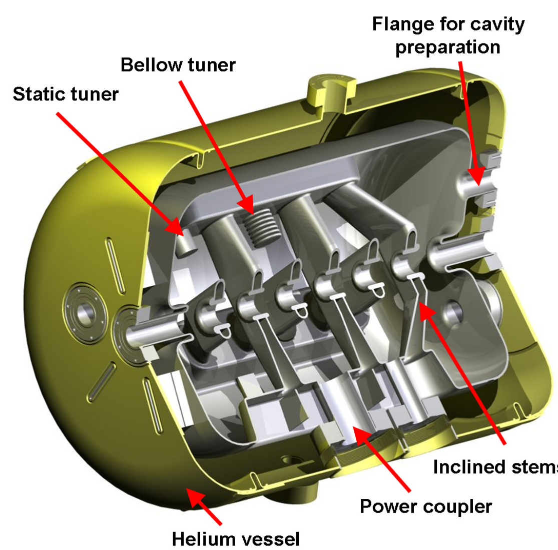

Figure 5: Geometry of the superconducting 325 MHz CH-cavity which is presently under fabrication.

are similar to the 325 MHz cavity. Mainly the number of accelerating cells and the frequency had to be adapted. Table 2 summarises the parameters of the 9 superconducting CH-cavities. The cavities have between 10 and 19 accelerating cells with constant length. Only the ration between gap and cell length has to be adjusted to reach a flat field distribution. The accelerating gradient is 5.1 MV leading to electric peak fields between 25 and 30 MV/m. Figure 6 shows the geometry of the first CH-cavity for the cw linac. The cavity is presently in the final design phase. It

Table 2: Parameters of the Superconducting Multi-gap Accelerating Cavities

Parameter	unit	C1	C2	C3	C4	C5	C6	C7	C8	C9
Gap number		15	17	19	10	10	10	10	10	10
Total length	mm	613	811	1054	636	642	726	726	813	862
Cell length	mm	40.8	47.7	55.5	63.6	64.2	72.6	72.6	81.3	86.2
Synch. veloctiy		0.059	0.069	0.080	0.092	0.093	0.105	0.105	0.118	0.125
Aperture diameter	mm	20	22	24	26	28	30	32	34	36
Eff. gap voltage	kV	225	274	317	356	362	408	411	459	538
Voltage gain	MV	3.13	4.14	5.42	3.27	3.30	3.73	3.73	4.18	4.43
Phase Factor $\cos\varphi_s$		0.93	0.89	0.90	0.92	0.91	0.92	0.91	0.91	0.82
Accelerating rate	$\mathrm{MV/m}$	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1

is planned to start the construction beginning of 2011. After cryogenic RF tests in Frankfurt the cavity will be tested with beam at GSI. The cavity will be powered by a 217 MHz 7.5 kW cw solid state amplifier which is already ordered. The tests will be performed in a new horizontal cryo module together with two 9 T superconducting solenoids (Fig. 7)

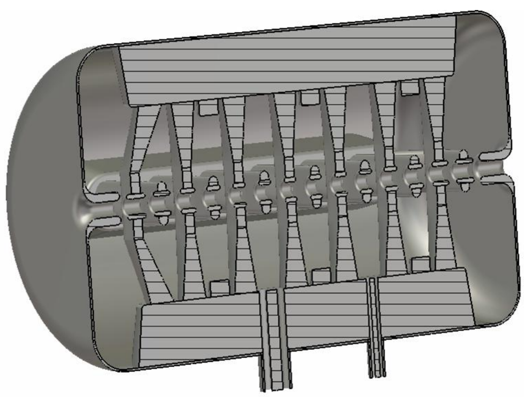

Figure 6: Geometry of the first CH-cavity for the cw linac.

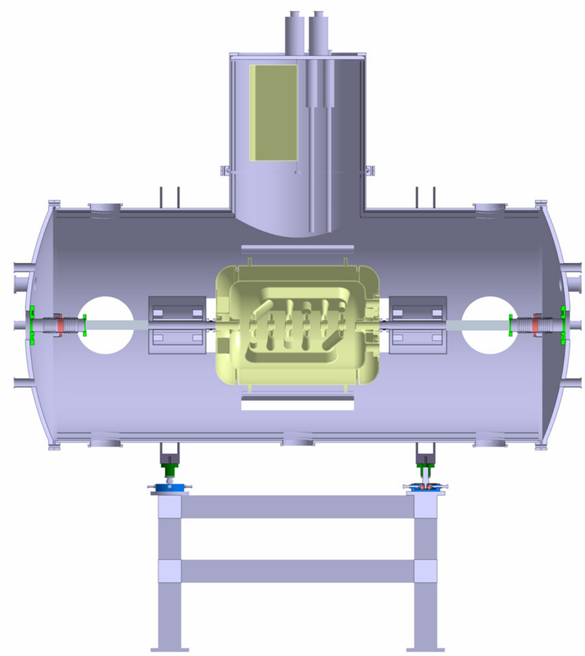

Figure 7: Layout of the horizontal cryo module equipped with CH-cavity and two superconducting solenoids.

SUMMARY

For the research with superheavy elements a cw operated superconducting heavy ion linac at GSI is proposed. The linac is based on multi-cell cavities of the CH-type at 217 MHz. The beam dynamics simulations show a good beam quality with small emittance growth when using the EQUUS-concept. In total 9 superconducting CH-cavities are required ranging from 1.4 AMeV to 7.3 AMeV. Presently one 325 MHz cavity is under fabrication and will be used to demonstrate the optimised geometry. The next cavity will be the original first CH-structure of the cw linac. Beam tests are foreseen 2012/2013 with the GSI High Charge Injector.

ACKNOWLEDGEMENT

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REFERENCES

[1] H. Podlech and others, "Superconducting CH-Structure", Physical Review Special Topics - Accelerators and Beams, **10**, 080101(2007)

[2] H. Podlech and others, "Development of the Superconducting CH-Cavity and Applications to Proton and Ine Acceleration", Proc. of the International Conference on RF Superconductivity, Beijing, China, 2007, pp. 48-52

[3] U. Ratzinger and others, Nucl. Inst. and Methods Phys. Res., Sect. A **415**, 229(1998)

[4] S. Minaev and others, "Superconducting, Energy Variable Heavy Ion Linac with Constant β, Multi-cell Cavities of CH-Type", Physical Review Special Topics - Accelerators and Beams, **12**, 120101(2009)