BEAM DYNAMICS FOR THE SC CW HEAVY ION LINAC AT GSI*

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Abstract

For future experiments with heavy ions near the coulomb barrier within the SHE (super-heavy elements) research project a multi-stage R&D program of GSI, HIM and IAP is currently in progress [1]. It aims at developing a superconducting (sc) continuous wave (cw) LINAC with multiple CH cavities as key components downstream the High Charge Injector (HLI) at GSI (Fig. 1). The beam dynamics concept is based on EQUUS (equidistant multigap structure) constant-β cavities. Advantages of its periodicity are a high simulation accuracy, easy manufacturing and tuning with minimized costs as well as a straightforward energy variation. The next milestone will be a full performance beam test of the first LINAC section, comprising two solenoids and a 15-gap CH cavity inside a cryostat (Demonstrator).

INTRODUCTION

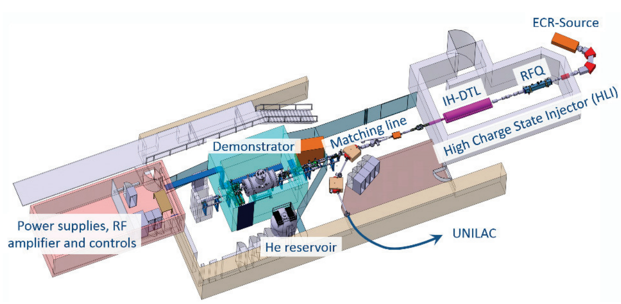

Figure 1: CH cavity test environment for a full performance test of the sc cw LINAC Demonstrator at GSI (first expansion stage with max. two cavities and one cryostat).

The beam dynamics concept for the sc cw LINAC is based on EQUUS, as proposed in [2]. It features high acceleration efficiency with longitudinal and transversal stability, as well as a straightforward energy variation. The latter can easily be achieved by varying the applied rf voltage (even down to “switched off“ cavities) or the rf phase of the amplifier. Highly charged ions with a mass-to-charge ratio of up to 6 will be accelerated from 1.4 MeV/u up to 3.5 - 7.3 MeV/u. A typical ion species for acceleration is $^{48}Ca^{10+}$ (with an A/q of 4.8) as projectile for hot fusion reactions with actinide targets [3]. Energy variation whilst maintaining a high beam quality is the core issue with respect to beam dynamics. Therefore research has been started to optimize the present conceptual layout of a sc cw-LINAC by Minaev et al. [2].

BEAM DYNAMICS SIMULATIONS

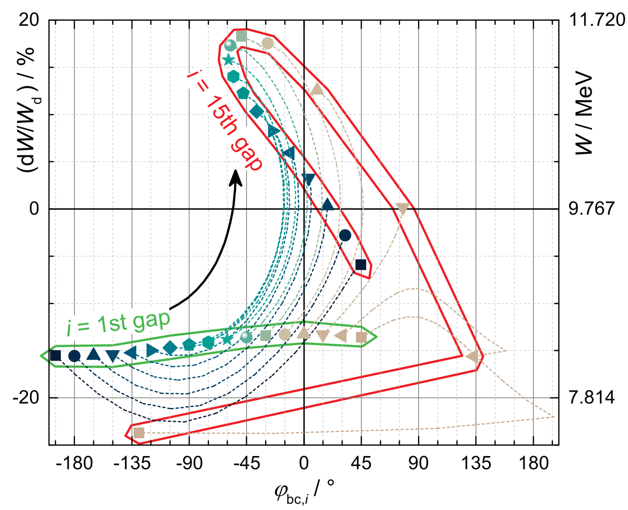

Figure 2: Movement of the bunch-center particle in longitudinal phase space in dependence of the initial phase $\varphi_{\mathrm{bc},1}$ while traversing the 15-gap CH cavity.

Inside an EQUUS cavity cell lengths are kept constant and are designed with a higher (geometrical) β than the one of the injected beam (also called “constant-β structure“). This leads to a sliding movement in longitudinal phase space. Trajectory and energy gain depend strongly on the initial phase at the first gap center $\varphi_{\mathrm{bc},1}$ and the difference between particle energy W and design energy W_{d}. Figure 2 shows this movement for the 15-gap CH cavity whose construction is nearly completed [4]. At $\varphi_{\mathrm{bc},1} = -30°$ the highest energy gain is achieved ($\Delta W = 3.1$ MeV), while at $-60°$ it has the highest symmetry. The corresponding emittance evolution is plotted in Fig. 3 showing a broad range of little growth. All simulations in this paper have been performed with LORASR [5] and will be prospectively benchmarked with TraceWin [6] and bender [7]. 10k particles with $q = 1$, $m = 6\,\mathrm{u}$ and $I = 0\,\mathrm{mA}$ were used as input distribution (Fig. 4), starting downstream the HLI IH-DTL (Fig. 5).

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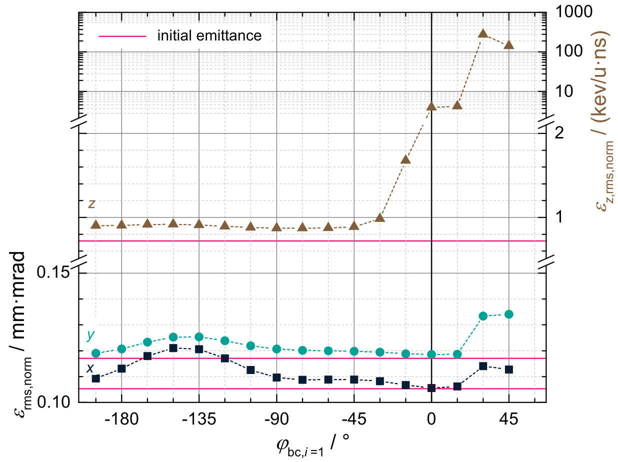

Figure 3: Normalized output rms-emittance in x, y and z depending on the initial phase at the first gap center. Particles with a phase deviation $> 360°$ to the synchronous/reference particle reach the following bunch and are therefore shifted by $-720°$. This leads to a much bigger emittance ellipse area and is the reason for the emittance blow up for $\varphi_{\mathrm{bc},1} \geq 30°$. The bunch in longitudinal phase space is shown in Fig. 8.

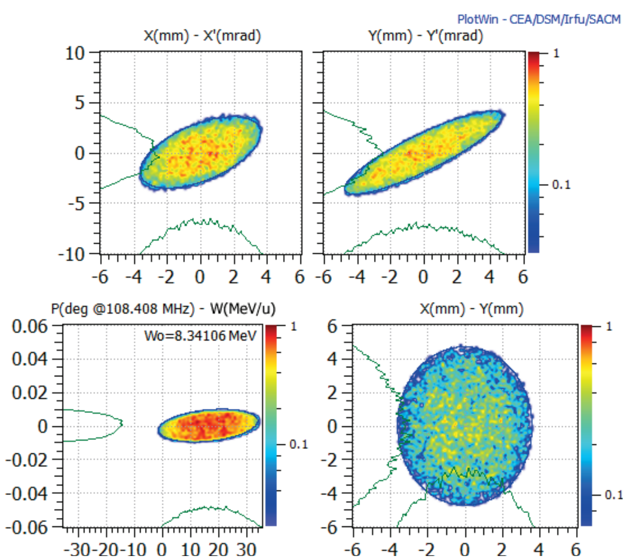

Figure 4: Theoretical distribution downstream the IH-DTL used as input distribution for the cw-LINAC matching line.

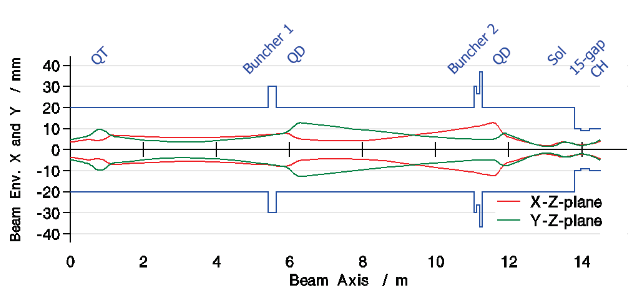

Figure 5: Transverse beam envelopes in the matching line downstream the HLI IH-DTL simulated with LORASR.

Table 1: Design Parameters of the cw-LINAC

Parameter	Unit	Value
Mass-to-charge ratio		≤ 6
Frequency	MHz	216.816
Max. beam current	mA	1
Injection energy	MeV/u	1.4
Output energy	MeV/u	3.5 - 7.3
Output energy spread	MeV/u	±3

OPTIMIZED ADVANCED DEMONSTRATOR

The Advanced Demonstrator (Fig. 6, [8]) was proposed as intermediate step towards the whole cw-LINAC. Shorter CH cavities (see [9], Table 2 and Fig. 9) with 8 instead of 10 - 19 gaps and inside shorter cryostats (containing 2 identical instead of 5 different cavities) could provide several advantages:

- broader velocity acceptance
- higher tolerance regarding frequency and field deviation
- lower technological risk during manufacturing
- shorter cryostats for easier mounting and maintenance
- more robust beam dynamics (particularly longitudinal)
- warm magnetic quadrupoles easier to handle than SC solenoids with respect to quenching and magnetic shielding
- more options for diagnostic elements between cryostats

In the Optimized Advanced Demonstrator the movement in longitudinal phase space (see Fig. 2) would be splitted in two parts. Roughly speaking the phase slip starts in positive direction inside the first, and reverses towards negative phases when traversing the second cavity of a cryostat. Ultimately this could open up more flexibility in shaping the beam with regard to the experimental needs (Table 1). Therefore this approach for an Optimized Advanced Demonstrator (Fig. 7) will be further investigated. The concept is also reflected in the new reference design (2014) for the MYRRHA injector [10], which features a short EQUUS CH cavity approach with up to 8 gaps per cavity.

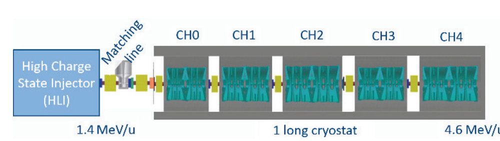

Figure 6: Initial Advanced Demonstrator layout.

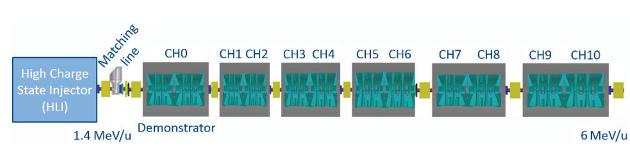

Figure 7: Optimized Advanced Demonstrator layout draft.

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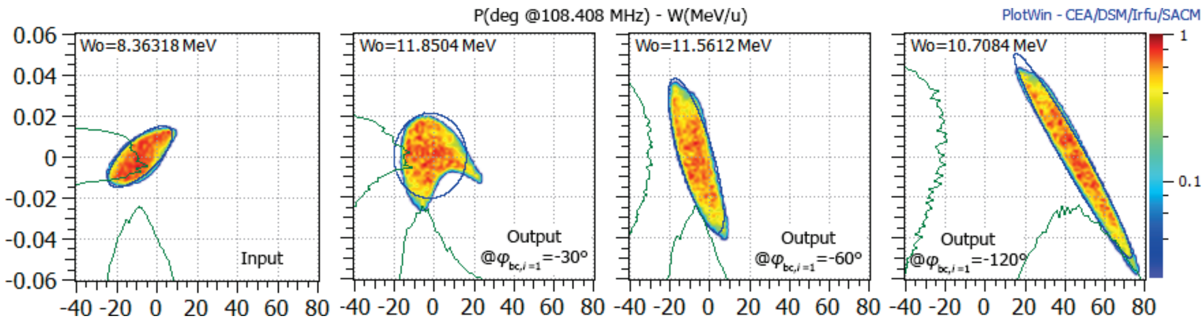

Figure 8: A bunch in the longitudinal phase space at the entrance *(left)* and exit of the 15-gap CH cavity in dependence of the initial phase at the first gap center $\varphi_{\mathrm{bc},1}$.

Table 2: Main Parameters of the 8-gap CH Cavity

Parameter	Unit	Value
β (design)		0.069
Frequency (matching line)	MHz	108.408
Frequency	MHz	216.816
Gaps	#	8
Total length	mm	593
Cavity inner diameter	mm	399.4
Aperture diameter	mm	30
Dynamic bellow tuner	#	2
Static tuner	#	3
Accel. Gradient	MV/m	5
U_{a}	MV	1.8
$E_{\mathrm{p}}/E_{\mathrm{a}}$		<7
$B_{\mathrm{p}}/E_{\mathrm{a}}$	mT/(MV/m)	<10
R/Q	Ω	1081

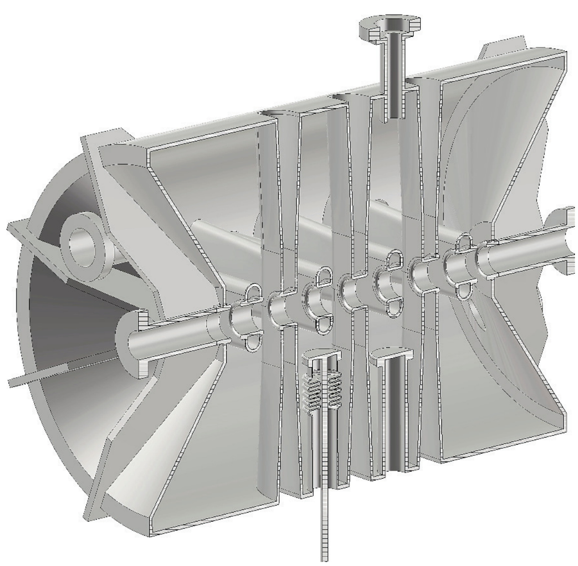

Figure 9: Sectional side view of the 8-gap CH cavity in CST MICROWAVE STUDIO.

CONCLUSION

A multi-stage R&D program is currently in progress to build a sc cw heavy ion LINAC at GSI. Short CH cavities with EQUUS constant-β beam dynamics turn out as an promising approach with numerous advantages. The next step is a performance test of the 15-gap CH cavity embedded in the Demonstrator cryostat. Integration of the 8-gap cavity in the cryostat will be the following milestone especially to test energy variation possibilities.

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