A Superconducting 217 MHz Single Spoke Cavity for the Helmholtz Linear Accelerator at GSI

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Abstract:

A new superconducting (SC) continuous wave (CW) linac, providing high efficient heavy ion acceleration above the coulomb barrier, is going to be built at GSI to fulfill the upcoming demands in the research field of super heavy element (SHE) synthesis. The so called HELIAC (HElmholtz LInear ACcelerator) delivers ion beams in the energy range of 3.5 MeV/u and 7.3 MeV/u with a mass to charge ratio (A/z) of up to 6. Superconducting multi-gap crossbar-H-mode (CH) cavities with a resonance frequency of 217 MHz are used for beam acceleration. In addition, SC single spoke buncher cavities should ensure longitudinal beam matching to the following CH sections. Therefore, the first 217 MHz single spoke cavity with β = 0.07 has been developed at HIM/GSI. In this paper the design of the cavity and first RF measurements during manufacturing are presented.

Layout of the Single Spoke Resonator (SSR)

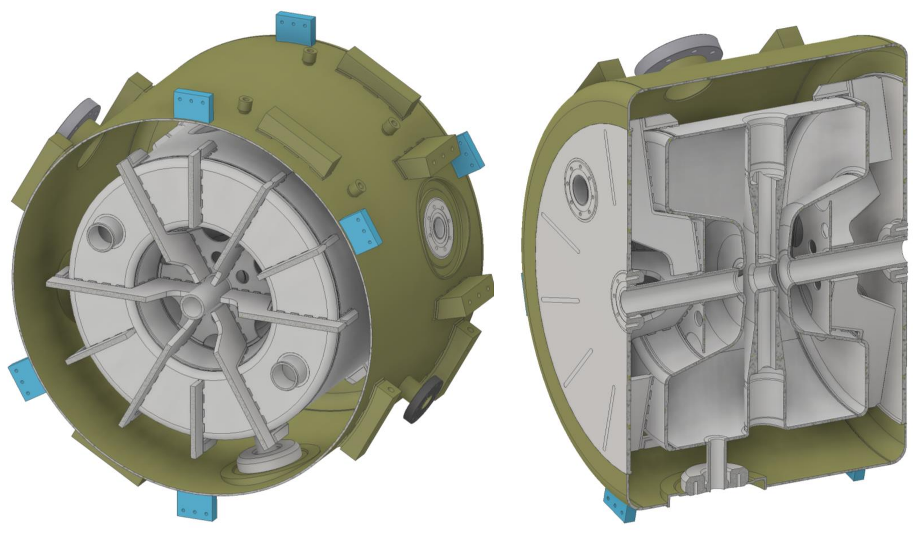

Figure 1: Layout of the superconducting 217 MHz SSR.

Table 1: Main parameters of the cavity

PARAMETER	UNIT	VALUE
β (v/c)		0.07
Frequency	MHz	216.816
Effective length (βλ)	mm	97
Gap length	mm	13
Total length	mm	416
Total diameter	mm	565
Tube aperture	mm	30
R_a/Q_0		140
E_a (design)	MV/m	5.5
E_p/E_a		6.1
B_p/E_a	mT/(MV/m)	8.9

Sequential Assembly of Bare Buncher Cavity

End Cap Tuning

- Successively frequency tuning by oversized end cap trimming (Δf = -1.5 MHz/mm)

Virtual Welding

- **Frequency mismatch of +2.1 MHz** due to insufficient welding shrinkage **→ compensated by virtual welding**

Frequency Tuner

- Dynamic bellow tuner for slow & fast frequency adjustment at 4 K
- Measured tuning range at 293 K: Δf = ±110 kHz/mm

Frequency After Final Welding

- f = 214.720 MHz (0.05 % < simulated)

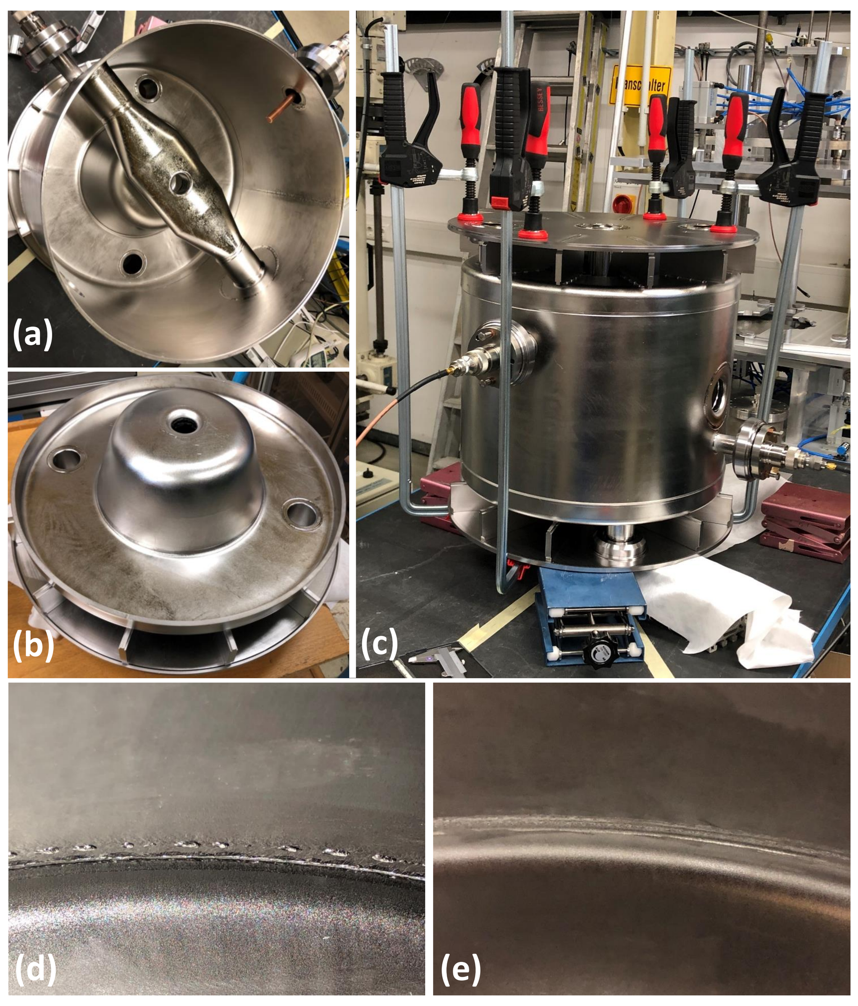

Figure 2: Open SSR (a) before attachment of trimmed end cap (b). Temporarily assembled cavity for RF tuning (c). Weld spatter on RF surface after virtual welding (d) and surface improvement after polishing/grinding (e).

Figure 3: Dynamic tuner partially welded.

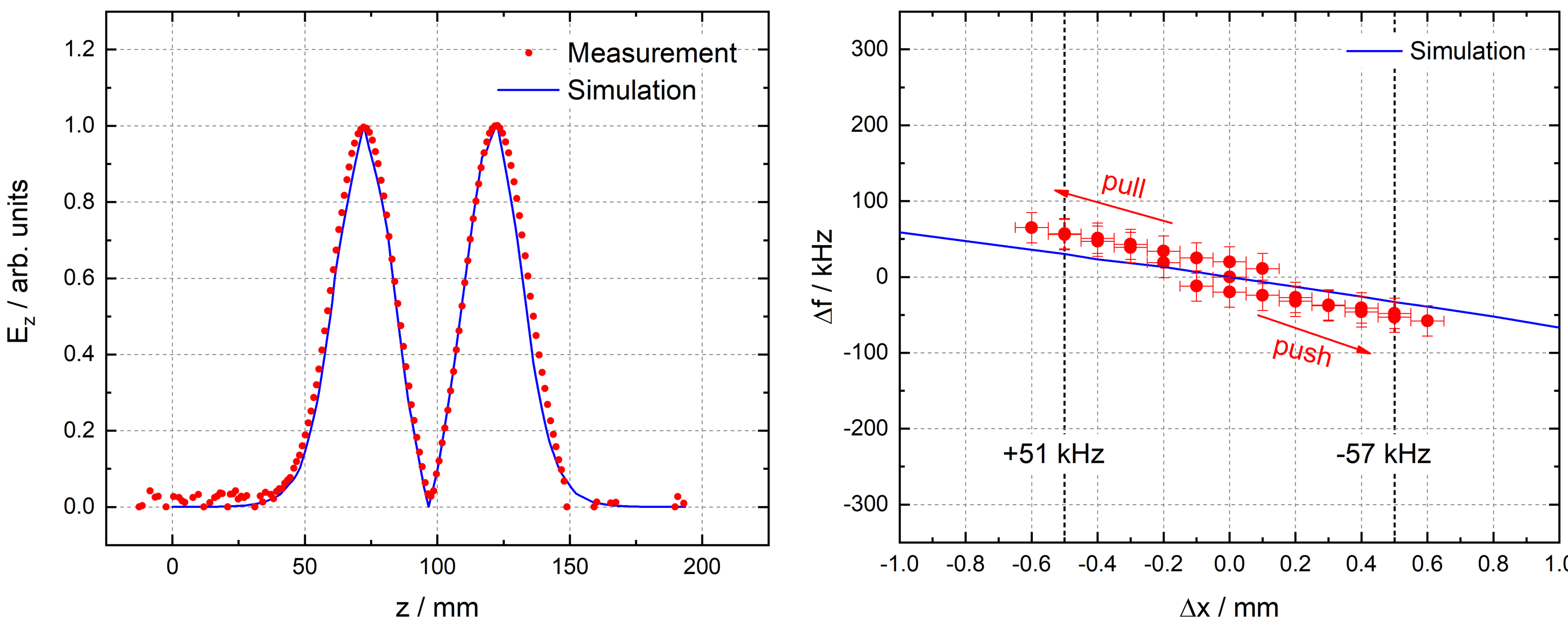

Figure 4: Bead-pull measurement of the electric field distribution along the beam axis for the bare cavity (left) and measured frequency shift of the dynamic tuner (right).

Evacuation & Cool Down

first assumption

f_{Target} @ 4K under vacuum = 216.816 MHz

214.831 MHz + 0.042 MHz – 0.112 MHz + 0.064 MHz + 1.42 MHz = 216.245 MHz

f_{Design}	df/dT	df/dp	ε_r	200 µm BCP (7 kHz/mm)	570 kHz reserve

Boundary Conditions for Simulations

- Drift surface of the spoke and tuner were chosen as a fixed support
- 1 bar pressure on the cavity walls was adopted as applied load
- Assumption: self-supporting cavity during evacuation process
- Asymmetrical thermal shrinkage → stable in y-plane, shrinking in x,z-plane
- Thermal shrinkage and frequency shift determinded by total linear contraction

Figure 5: Evacuation of the cavity at room temperature.

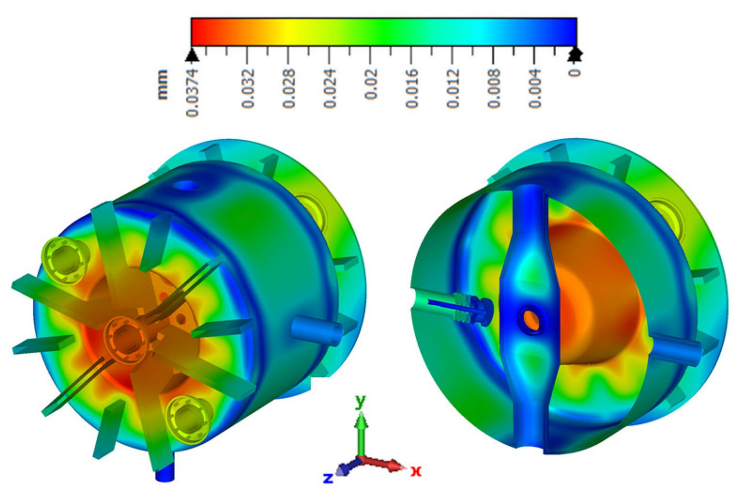

Figure 6: Deformation of the SSR due to 1 bar pressure difference.

Table 2: Wall thickness of individual cavity components.

WALL THICKNESS	SPOKE & CAVITY TANK	END CAP	DISC HELIUM JACKET
mm	4	5	6

Table 3: Influences on the cavity due to evacuation and cool down

EVACUATION	UNIT	SIMULATION	MEASUREMENT
Max. displacement end cap	µm	0.37	-
Max. von Mises stress	MPa	59	-
Δf	kHz	-48	-91
df/dp	Hz/mbar	-112	-155
COOL DOWN	**UNIT**	**SIMULATION**	**MEASUREMENT**
Longitudinal (z-plane) shrinkage @ 4 K	mm	0.6	-
Transverse (x-plane) shrinkage @ 4 K	mm	0.6	-
Δf @ 4 K	kHz	42	-
Δf @ 77 K	kHz	27	38

Figure 7: The cavity was installed vertically in a tub filled with LN_2.

Surface Preparation & Cavity Finalization

Surface Treatment Recipe

- 7x Buffered Chemical Polishing (BCP) for surface improvement (12 kHz/µm, 230 µm, Δf = +2.8 MHz)
- BCP used for final frequency tuning
- 650 °C baking for 24 h avoiding *Q*-disease and hydrogen contamination
- Helium jacket integration
- High Pressure Rinsing (HPR) for 15 h to reduce field emission

Status Quo & Outlook

- Cavity delivered to HIM in 04/2022
- Target frequency finally reached within the dynamic tuner range: f = 216.715 MHz (in vacuum at 293 K)
- First performance tests at 4 K with low-level RF power planned in Q4 2022

Figure 8: Final SSR with helium jacket before shipment to HIM in April 2022.

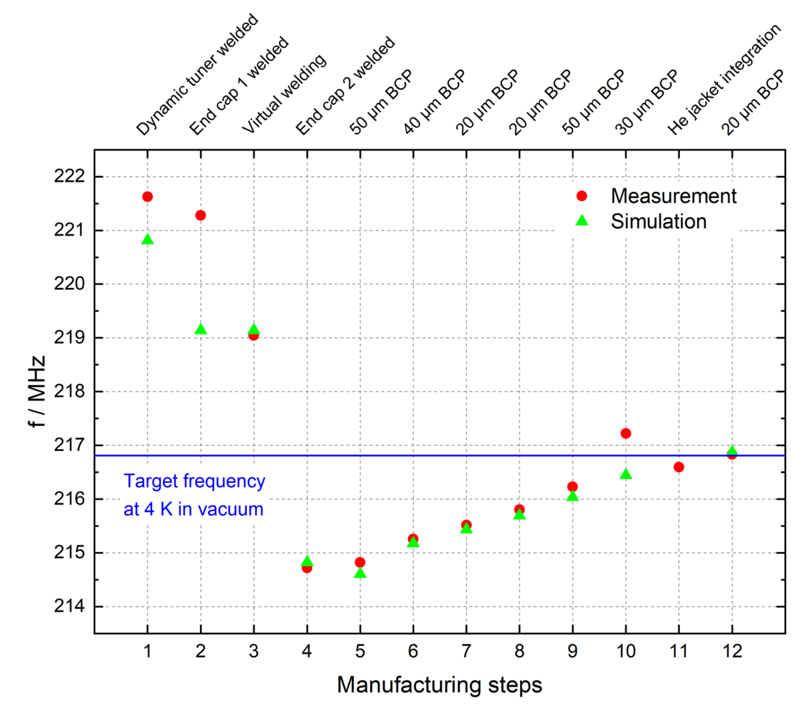

Figure 9: Measured resonance frequency of the cavity during different steps of manufacturing.