

R&D STATUS OF THE NEW SUPERCONDUCTING CW HEAVY ION LINAC@GSI

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Abstract

To keep the ambitious Super Heavy Element (SHE) physics program at GSI competitive a superconducting (sc) continuous wave (cw) high intensity heavy ion LINAC is currently under progress as a multi-stage R&D program of GSI, HIM and IAP [2]. The baseline linac design consists of a high performance ion source, a new low energy beam transport line, an (cw) upgraded High Charge State Injector (HLI), and a matching line (1.4 MeV/u) which is followed by the new sc-DTL LINAC for post acceleration up to 7.3 MeV/u. In the present design the new cw-heavy ion LINAC comprises constant-beta sc Crossbar-H-mode (CH) cavities operated at 217 MHz. The advantages of the proposed beam dynamics concept applying a constant beta profile are easy manufacturing with minimized costs as well as a straightforward energy variation [6]. An important milestone will be the full performance test of the first CH cavity (Demonstrator), in a horizontal cryo module with beam. An advanced Demonstrator setup comprising a string of cavities and focussing elements is proposed to build from 10 short CH-cavities with 8 gaps. The corresponding simulations and technical layout of the new cw heavy ion LINAC will be presented.

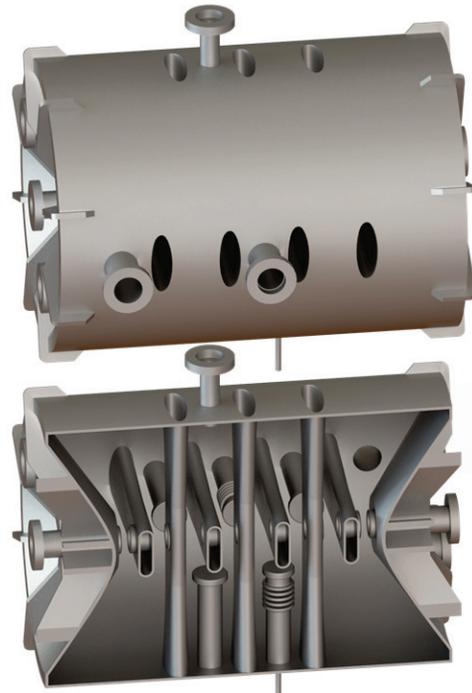


Figure 1: Layout of the sc 217 MHz CH-cavity.

Table 1: Main Parameters of the 217 MHz CH-cavity

Parameter	Unit	
β		0.069
Frequency	MHz	215
Accelerating cells		8
Length ($\beta\lambda$ -definition)	mm	381.6
Cavity diameter (inner)	mm	392.3
Cell length	mm	47.7
Aperture diameter	mm	30
Static tuner		3
Dynamic bellow tuner		2
Wall thickness	mm	3-4
Accelerating gradient	MV/m	5
E_p/E_a		5.2
B_p/E_a	mT/(MV/m)	<10
G	Ω	50
R_a/Q_0	Ω	1070

INTRODUCTION

At the moment the Demonstrator for the sc cw-LINAC at GSI is under construction and its successful beam operation will be the first milestone realizing the new sc cw-LINAC at GSI [1]. The advanced Demonstrator which is presented here will be the second milestone for the sc LINAC at GSI. The Demonstrator will be the first cavity for the sc LINAC followed by 5 additional cryomodules with 2 CH-cavities per cryomodule [2,3]. The design of the advanced Demonstrator will be used for all cavities in the sc cw-LINAC after the Demonstrator. The 8 cell cavity is designed and optimized for high power applications and has a design gradient of 5 MV/m. Its frequency is the second harmonic of the High Charge Injector (HLI) at GSI, Darmstadt. Table 1 shows the main parameters and figure 1 shows the Layout of the sc 217 MHz CH-cavity.

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MULTIPACTING

The phenomenon of multipacting is a crucial point for sc accelerating structures. To find possible areas where multipacting can occur several simulations with CST particle studio [4] have been performed. Critical areas where multipacting can occur are the tuners. The space between tuners and stems is narrow and can provide resonance conditions for multipacting. Also the gaps of the bellow tuner provide areas where multipacting can build up. To investigate if multipacting conditions are fulfilled in these areas the secondary emission yield was simulated with particle sources in CST particle studio [4] for the different parts of the cavity. The secondary emission yield is defined as:

$$SEY = \frac{\text{current emitted due to secondary electrons}}{\text{current absorbed due to particle collisions}}$$

This ratio indicates if electron multiplication is present or not. If the secondary emission yield is above 1, then more electrons are produced than absorbed which resolves in multipacting. If it is below 1, no electron avalanche can build up and no multipacting will occur. Of course multipacting can occur on different energies stored in the cavity. So the secondary emission yield has to be simulated for increasing accelerating gradients. The simulation results [4] for the two dynamic tuners and the cavity walls are shown in figure 2.

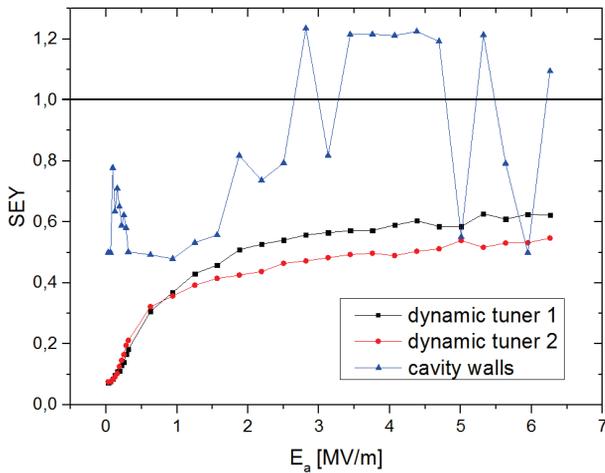


Figure 2: Simulated secondary emission yield for dynamic tuners and cavity walls.

It can be seen, that multipacting occurs only on the cavity walls. Shown also by the particle trajectories in Figure 3. Probably no multipacting will arise in the dynamic tuners itself or between the tuners and the stem, assuming a tuner diameter of 35 mm. Simulations have been performed also for larger diameters. The simulations show multipacting resonances for accelerating gradients below 1 MV/m. To avoid these critical conditions the tuner diameter is fixed on 35 mm for the final design.

The secondary emission yield obviously depends on the material properties. To compare the influence of the material characteristics the secondary emission yield was evaluated

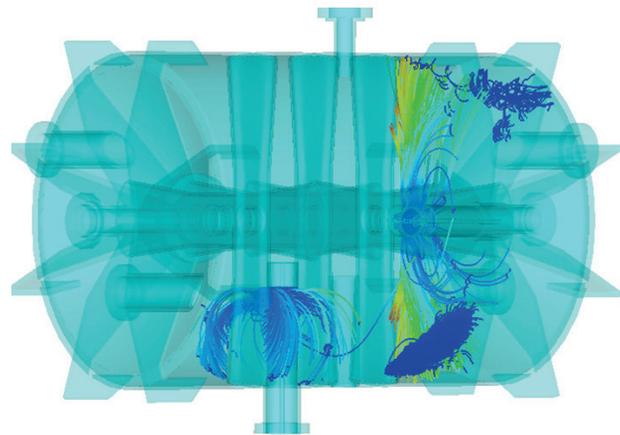


Figure 3: Particle trajectories generated by CST Particle Studio [4].

for niobium with three different surface preparations. The worst preparation scheme is a "wet treatment" of the niobium surfaces which are only high pressure rinsed. Additionally surface prepared cavities as "300°C bakeout" and "argon discharged" have been simulated. The different secondary emission yields as function of the accelerating gradients for the cavity walls are shown in figure 4.

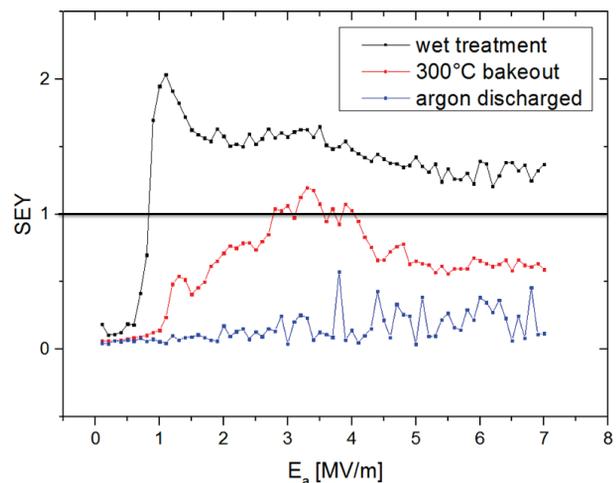


Figure 4: Simulated secondary emission yield for different cavity preparation schemes.

The impact of the surface preparation on the secondary emission yield and the multipacting can clearly be seen. The expected condition for the final sc 217 MHz CH-cavity should be at least 300°C bakeout so that multipacting on the cavity walls may only arise while increasing the accelerating gradient. For the desired maximum field gradient of 5 MV/m the estimated secondary emission yield does not indicate risks of multipacting.

TUNING CONCEPT

Due to the fact that superconducting cavities have a very sharp resonance curve it is essential that the desired frequency can be reached and kept constant during operation. A tuning system with static tuners and dynamic tuners is required for stable operation. The sc 217 MHz CH-cavity has 3 static and 2 dynamic tuners which have been basically designed and optimized with CST Microwave Studio [4]. Due to the limited tuner diameter of 35 mm the tuning range for the static as well as for the dynamic tuners was increased by tuner heads. To guarantee safe operation at 217 MHz the dynamic tuners should cover at least a tuning range of 250 kHz. The maximum elongation of the dynamic tuners is 1 mm. A further elongation is hazardous concerning damaging the tuners (wall thickness of 1 mm only). To achieve a frequency range of 250 kHz per mm different tuner head diameters (35 mm to 50 mm) have been simulated. The results are shown in figure 5.

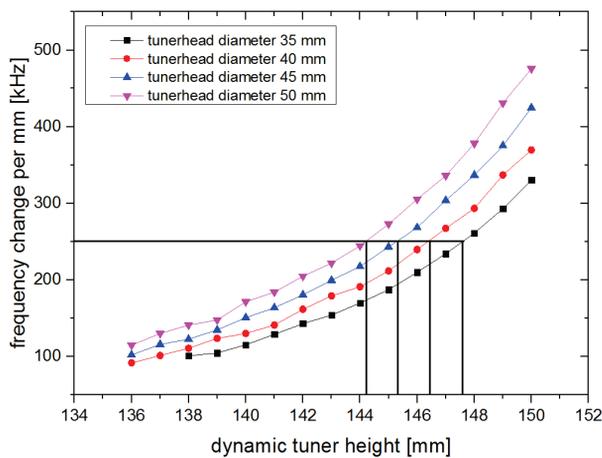


Figure 5: Frequency change per mm for different tuner heads.

The important values of the sc 217 MHz CH-cavity are the E_p/E_a and B_p/E_a ratios. The impact of the different tunerhead diameters on the E_p/E_a ratio can be seen in figure 6.

The E_p/E_a ratio gets better with increasing tuner head diameter for a fixed frequency change per mm of 250 kHz. This is due to the fact that the necessary tuner height decreases with increasing tuner head diameter. The maximum electric fields between the dynamic tuners and the stems are decreasing. On the other hand the tuner heads are getting closer to the stems with increasing tuner head diameter which is raising the maximum magnetic fields. In the final design the tuner head diameter for the dynamic tuner was set to 45 mm. Thermal shrinkage of the cavity as well as buffered chemical polishing increase the frequency of the sc 217 MHz-cavity. The static tuners should provide 70% to 80% of the tuning range to decrease the frequency and 30% to 20% to increase the frequency. The frequency can also be increased with additional steps of chemical polishing. The tunerhead for the static tuners was set to 50 mm to guarantee

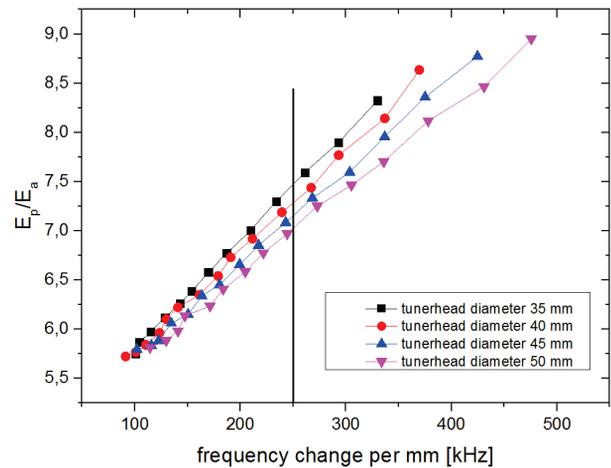


Figure 6: E_p/E_a ratio dependent on frequency changer per mm.

a sufficient tuning range of 2,3 MHz. The tuning ranges for the different tunerhead diameters is depicted in figure 7.

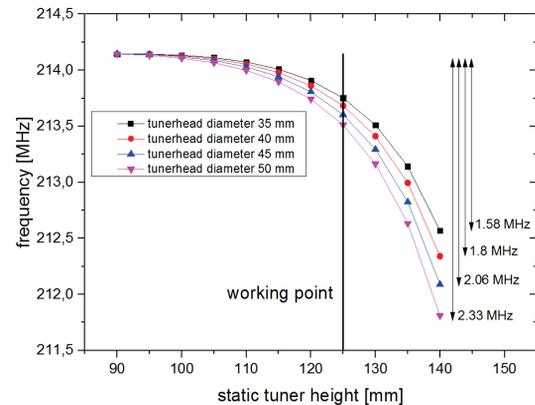


Figure 7: Tuning range static tuner.

NEW BELLOW TUNER DESIGN

The performed simulations on the risk of multipacting limited the tuner diameter to 35 mm. To decrease the number of fins needed for a tuner stroke of 1 mm the design of the dynamic tuners was revised. For the old tuner design (diameter of 35 mm) at least 4 fins with a gap distance of 3 mm were necessary to achieve a tuner stroke of 1 mm without raising the Von-Mises-Stress above 0.25 GPa. Although the multipacting simulations show no discrete multipacting conditions in the planar areas of the dynamic tuner it is desirable to have as less fins as possible. To achieve a tuner stroke of 1 mm with less fins the design of the dynamic bellow tuner was changed so that the diameter of the fins is the same as the tunerhead. This is possible because the neighbouring stems are getting smaller from the cavity walls to the beam axis so that the space between fins and stems is still uncritical for construction and multipacting. A comparison between the old and the new design is shown in figure 8.

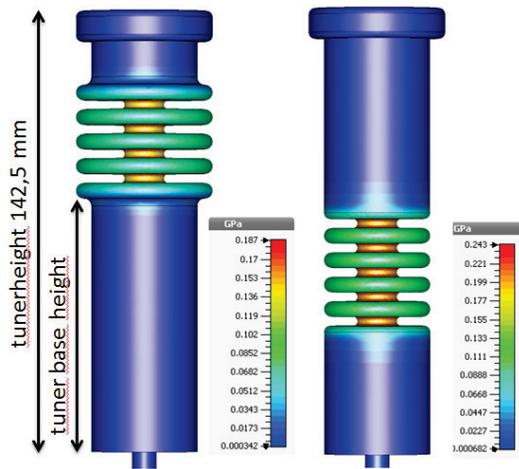


Figure 8: New (left) and old (right) design of the dynamic bellow tuner.

The old design needs at least 4 fins to achieve a tuner stroke of 1 mm and the Von-Mises-Stress arises to 0.24 GPa. In the new design only 3 fins are necessary to perform a tuner stroke of 1 mm and the maximum Von-Mises-Stress is in the range of 0.19 GPa only. The improved design provides more safety for operation. It is possible to perform a tuner stroke of more than 1 mm without damaging the tuner. The yield strength for niobium in cold conditions is in the range of 0.47 GPa. But in general the Von-Mises-Stress should not exceed 0.25 GPa.

Due to the fact that the dynamic tuners are made of 1 mm thick niobium they are vulnerable to vibrations. It is necessary to investigate the eigenfrequencies of the tuner itself. This was done with the simulation program AnsysWB [5]. The tuner height is determined by the tuning range needed for safe operation, the tuner diameter is determined by the multipacting simulations and the number of fins and the gap distance between two fins is determined by the necessary tuner stroke. The only parameter to influence the eigenfrequency is the position of the fins on the tuner. The height from the bottom of the tuner to the first fin was increased and the change in the first 10 eigenfrequencies was simulated. The results for the first eigenmode of the old design and the first eigenmode of the new design is depicted in figure 9.

The operation of vacuum pumps or tuner drives attached to the cavity may cause interfering vibrations. All these disturbances are in the range of up to a few hundred Hz. The next eigenmodes of the dynamic tuners are above 500 Hz and not interesting for further investigations. The eigenfrequency is increasing when the fins are attached near the tunerhead. The new design provides higher eigenfrequencies further away from critical low frequencies (see figure 9).

CONCLUSION

The simulations show that in critical regions of the cavity like the dynamic tuners multipacting should not occur. Multipacting should only arise on the cavity walls while the accelerating gradient is increasing. The tuning concept with

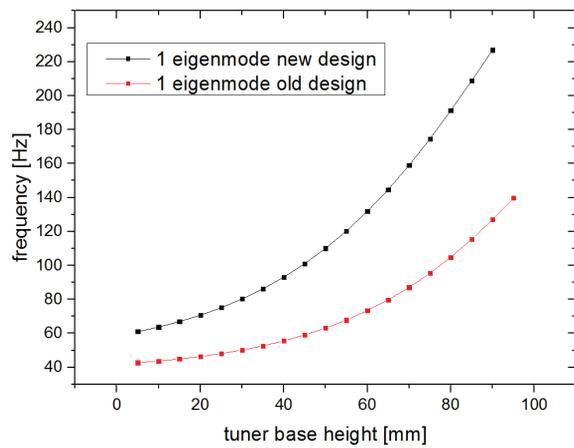


Figure 9: Eigenfrequencies for the first two eigenmodes.

3 static and 2 dynamic tuners assures to reach the design frequency and keep it stable. The tunerheads have been optimised concerning the tuning range and parameters like the E_p/E_a ratio. The design of the dynamic tuners has been revised to decrease the number of fins and the maximum Von-Mises-Stress. The new design provides higher eigenmode frequencies and three fins only for a tuner stroke of 1 mm or even more. The basic design of the presented short CH-cavity could also be used for the 17 MeV MYRRHA injector of the MAX-project, adjusted for a frequency of 176.1 MHz [7].

ACKNOWLEDGEMENT

This work has been supported by Helmholtz-Institut Mainz (HIM) and Gesellschaft für Schwerionenforschung (GSI).

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