HIGH GRADIENT CH-TYPE CAVITY DEVELOPMENT FOR 10 – 100 AMeV BEAMS*

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Abstract

The activities in pulsed linac development aim on compact designs and on an increase of the voltage gain per meter. At IAP - Frankfurt, a 325 MHz CH - cavity is under construction, where the mean effective accelerating field is expected to reach well above 10 MV/m at an energy of 12.5 AMeV corresponding to β=0.164. Within a funded project, this cavity is systematically developed. Currently, the cavity is under construction at NTG GmbH and expected to be ready for copper plating in autumn 2014. The results should give an impact on the rebuilt of the UNILAC - Alvarez section – aiming to achieve the beam intensities specified for the GSI – FAIR project. A mid - and long - term aim is the development of a compact, pulsed high current linac. The new GSI 3 MW Thales klystron test stand will be very important for these investigations. Detailed studies on two different types of copper plating can be performed on this cavity. Additionally, operating of normal conducting cavities at cryogenic temperatures will be discussed for the case of very short RF pulses.

INTRODUCTION

Progress in pulsed power solid-state amplifier development opens the path towards compact low - beta linac designs. At higher frequencies beyond 600 MHz powerful klystrons are anyway available to continue such a strategy up to ion energies of several hundred AMeV. Separated function DTL technology and strategies for a minimization of the consequences from transverse rf defocusing have been developed during the last decades of heavy ion linac development. Moreover, high effective voltage gains beyond 10 MV/m in H – mode cavities with slim drift tube geometries have been demonstrated successfully at CERN Linac3 [1].

H – Mode cavities profit very much from slim drift tubes (see Fig. 1), as they concentrate the electric field on the drift tube structure. Thus, the stored energy is reduced efficiently by a small outer drift tube diameter, reducing surface damages in case of sparking.

In case of Crossbar H – type (CH) – structures the stem structure makes a larger partial contribution to the total capacity, and therefore, the drift tube effect is not as pronounced as for the Interdigital H – type (IH), but still important.

The development of room temperature CH – cavities was discussed in [2] in more detail. This paper is focusing on the development of CH – cavities towards a high field gradient.

This aspect is important for cases, where a compact linac for low duty factor applications is needed. Also, for high current operation the high field acceleration provides the needed longitudinal focusing forces.

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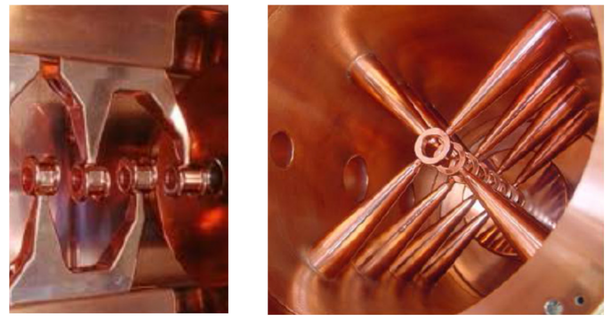

Fig. 1: IH – type (left) and CH – type (right) structure.

One main goal of this work is to prepare for the rebuilt of the high energy section of the GSI – Unilac, which will in future serve as heavy ion injector for the FAIR project.

STRUCTURE PERIOD LAYOUT

As an example how to apply this structure technology one typical lattice period is described in the following. It consists of an FDF quadrupole triplet followed by a 20 gap cavity and a DFD quadrupole triplet.

Table 1: Cavity Parameters for $^{238}U^{+28}$ Beams

Number of gaps	20
Freq. (MHz) / current (mA)	325.224 / 150
Energy range (AMeV)	12.16 – 13.71
Drift tube aperture (mm)	26
“Structure period” (mm)	2222.5
Quadrupole aperture (mm)	28
Effective pole length (mm)	145, 264, 145
Field gradients of the quadrupoles (T/m)	76, 75, 76

The transverse beam envelopes as well as the apertures are shown by Fig. 2.

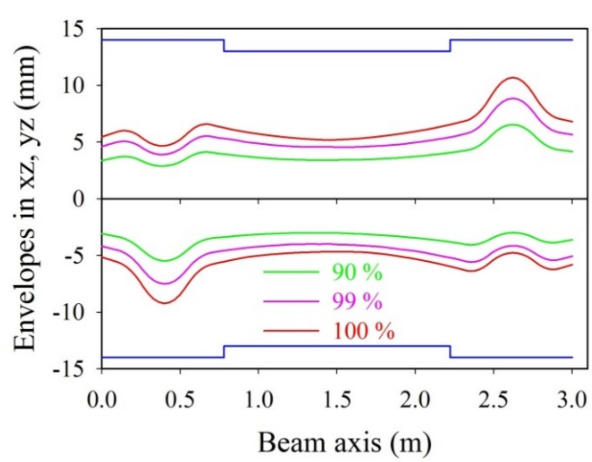

Fig. 2: Transverse beam envelopes along the 13.2 MV section for a 150 mA U28+ - beam.

A fixed - beta structure was used resulting in rf phases from - 47° to – 17° (Fig.3). The longitudinal focusing is provided mainly by the gaps close to the lenses, which allows to keep the apertures smaller against competitive negative synchronous phase designs. Fig. 4 shows that the longitudinal beam envelopes are very smooth. Finally, the cluster plots in the matched case are shown by Fig. 5.

The emittance growth along this section were 5 % in xx', 6 % in yy' and 1 % in zz', respectively, at a beam current of 150 mA, when assuming all buckets filled.

This concept will allow a high field and high current linac design based on lens free multi – cell cavities with constant period length and on quadrupole triplets. It is of interest for future pulsed proton linac concepts [3] as well as for pulsed heavy ion linacs.

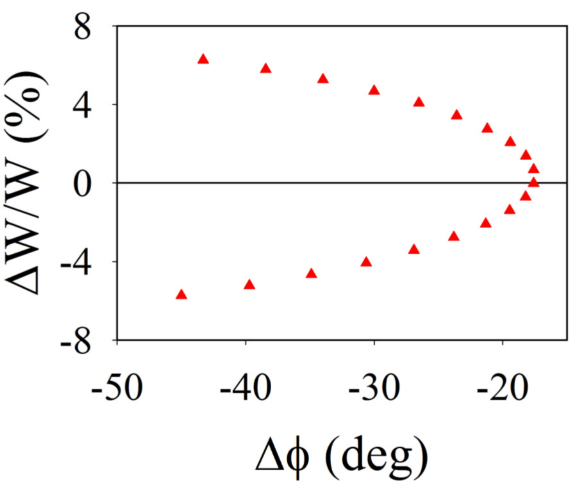

Fig. 3: RF phase of the bunch centre along the fixed beta profile with 20 gaps.

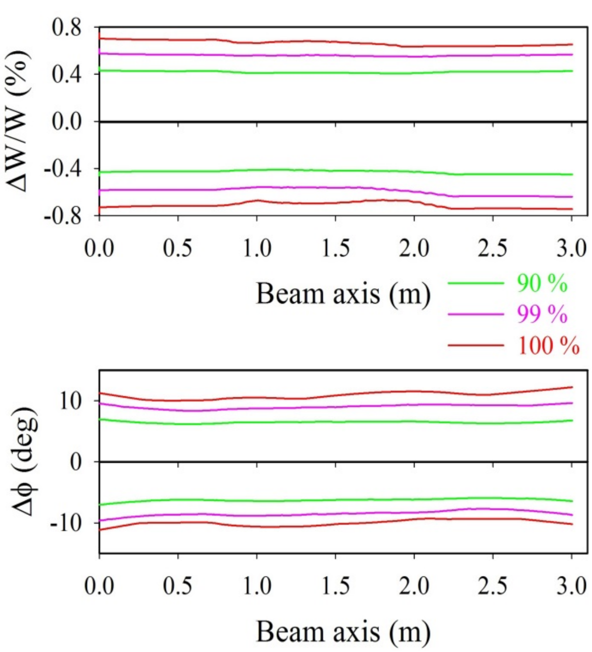

Fig. 4: Longitudinal beam envelopes.

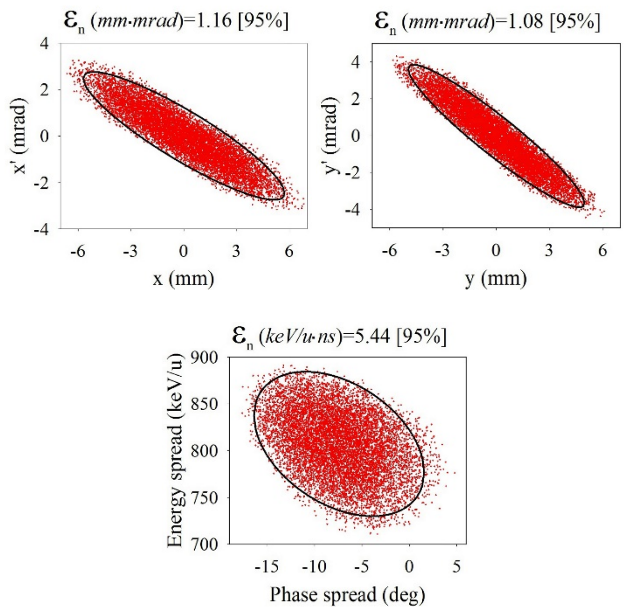

Fig. 5: Cluster plots at the following cavity entrance.

HIGH FIELD CAVITY

To test the field limits of a 325 MHz CH – cavity a 7 gap prototype is under development and shown by Fig. 6 [4].

The geometry was optimized for modest surface peak fields – reaching up to 97 MV/m at very small spots on the 1 mm^2- level.

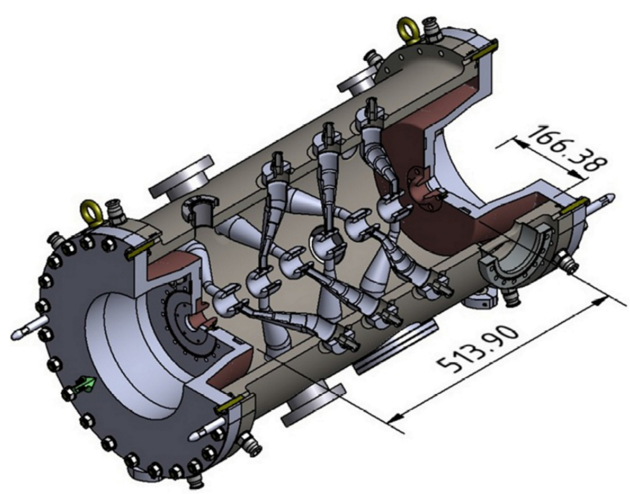

Fig. 6: 325 MHz high field prototype cavity with 7 gaps.

The central part is a monolithic stainless steel element, where the drift tube structure was welded into a massive cylindrical tank. The drift tube stems with drift tubes are directly water cooled, the outer cylinder has eight cooling channels in longitudinal direction. The end plates have one cooling channel each, the quadrupole triplets will be positioned in the accessible outer volumes. Metal gaskets will be used at each bolted joint.

Special care will be taken for the galvanic copper plating of the cavity. Two processes with different bath ingredients will be tested against each other at high rf power levels.

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Finally, the option of low temperature operation will be investigated as described below.

Table 2: Main Parameters of the High Field CH – Cavity

Number of Gaps	7
Frequency (MHz)	325.2
Voltage Gain (MV)	6
Eff. Accel. Length (mm)	513.90
Eff. Accel. Field (MV/m)	13.3
Power Loss (MW)	1.76
Q_0 – value	12476
Effective Shunt impedance (MΩ/m)	52.15
Drift tube aperture (mm)	27

LOW TEMPERATURE OPERATION

The exploitation of the enormous increase in copper conductivity at liquid nitrogen temperatures and below had inspired cavity designers since long - see for example ref. [5]. Unfortunately, the anomalous skin effect is reducing the advantage of rising conductivity as soon as the electron free path becomes as long or even longer than the skin depth (see table 3). At relatively low rf frequencies like in case of heavy ion structures and up to about 350 MHz there might be a potential for this kind of cryogenic cavities at very low duty factor:

As the surface resistivity is proportional to $\rho^{1/2}$, one might expect an rf power reduction of around factors 3 to 5 for the interesting frequency range below 350 MHz.

This would give an overall advantage as long as the spent, time averaged rf power to be cooled at cryogenic level is negligible against the cost advantage of reduced rf power installations needed for a specified effective acceleration field.

Table 3: Copper electrical resistivity (ρ), skin depth (δ) and mean free path (λ) values at different temperatures and at 300 MHz operating frequency.

T (K)	ρ (10^{-8} Ω·m)	δ (μm)	λ (μm)
300	1.725	3.80	0.03
77	0.197	1.31	0.24
60	0.097	0.89	0.54
40	0.0239	0.29	2.30

The time averaged temperature increase caused by the rf wall losses at different operating temperatures are given for a fixed wall thickness for the two cavity materials stainless steel and copper in Table 4. This effect gives another limit for the acceptable duty factors.

Table 4: Time averaged surface temperature increase at 100 μs, 100 Hz operation. Wall thickness is 2 mm in case of copper (Cu) and stainless steel (StS).

T (K)	P/A (W/m^2)	ΔT_{Cu} (mK)	ΔT_{StS} (mK)
300	3725.0	18.6	487
70	1258.8	4.5	318
60	883.8	2.2	266
40	438.5	0.4	188

Moreover, the temperature increase in the cavity surface during the rf pulse has to be known. This parameter as well the temperature distribution into the wall after a certain pulse duration can be estimated by applying the theory from ref. [6]. The numerical results show, that especially in case of stainless steel walls, the temperature rise during the pulse sets severe limits. In all cases, the simulations assumed the same rf voltage level by adjusting the rf power level accordingly. In case of stainless steel, the cavity surface was assumed to be copper plated.

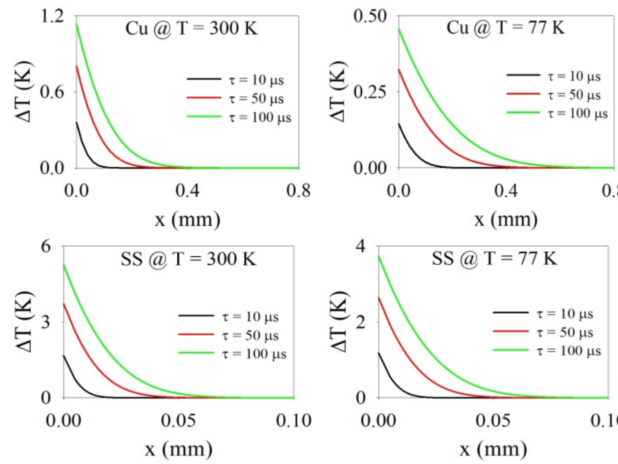

Fig. 7: Temperature profiles at the cavity surface at the end of specified pulse lengths.

CONCLUSION

As a result of progress in rf amplifier -, cavity surface - and cryogenic technology novel designs for short pulsed proton and heavy ion linacs become feasible, with effective averaged voltage gains around 10 MV/m.

At low beam energies adequate longitudinal beam gymnastics is required to stand such high gradients without a severe beam emittance blow - up.

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