STATUS OF A 325 MHz HIGH GRADIENT CH – CAVITY*

A. M. Almomani† and U. Ratzinger, IAP, Frankfurt University, Germany

Abstract

The reported linac developments aim on compact ion accelerators and on an increase of the effective accelerating field (voltage gain per meter). Within a funded project, a high gradient Crossbar H-type CH – cavity operated at 325 MHz was developed and successfully built at IAP – Frankfurt. The effective accelerating field for this cavity is expected to reach about 13.3 MV/m at a beam energy of 12.5 AMeV, corresponding to β=0.164. The results from this cavity might influence the later energy upgrade of the Unilac at GSI Darmstadt. The aim is a compact pulsed high current ion accelerator for significantly higher energies up to 200 AMeV. Detailed investigations for two different types of copper plating (high lustre and lustre less) with respect to the high spark limit will be performed on this cavity. The 325 MHz GSI 3 MW klystron test stand is best suited for these investigations. Additionally, operating of normal conducting cavities for the case of very short RF pulses will be discussed at cryogenic temperature.

INTRODUCTION

The maximum electric field gain for conventional DTL's is limited by thick walled drift tubes which are housing the focusing elements. Thus, high multipacting risks are expected on the plate capacitor like surfaces around the gaps. The stored energies as well as the risk of spark damages on the cavity surfaces are high. Consequently, quite modest operable field levels have to be chosen.

On the other hand, the slim drift tube geometries in H-mode cavities allow for high effective voltage gains beyond 10 MV/m. This has been demonstrated successfully at CERN linac 3, where the average effective voltage gain reached 10.7 MV/m at 1 ms pulse length [1].

The electric field in H-mode cavities like CH is concentrated on the drift tube structure by the slim drift tube design (Fig. 1). The development of CH – cavities was shown in detail in Ref. [2]. The development of a 70 MeV 70 mA proton linac based on CH – Cavities is currently performed at IAP – Frankfurt together with GSI and is designed with an average effective voltage gain of 3.5 MV/m

The main topic of this paper is focusing on the development of a high field gradient CH – structure [3-5]. These developments will be important in case of a compact linac for low duty factor applications. Moreover, for high current operation the high field gradient acceleration provides the needed longitudinal focusing forces.

Our motivation in this work is to prepare for a later upgrade of the high energy section of the GSI – Unilac. Another motivation is the development of an efficient and compact ion accelerator for medical hospitals where available space is quite limited and proton energies up to around 230 MeV are requested.

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† a.almomani@iap.uni-frankfurt.de

CAVITY DEVELOPMENT

To test the field gradient limits of a CH - cavity, a 325 MHz 7 gap prototype (Fig. 1) has been developed and successfully built at IAP – Frankfurt and was fabricated at NTG, Gelnhausen, Germany [3-6]. The structure geometry was optimized for an average effective field gradient reaching up to 13.3 MV/m at β = 0.164. The surface electric field levels are expected to reach about 95 MV/m at very small spots on the 1 mm^2 – levels [6]. The main cavity parameters are given in Table 1.

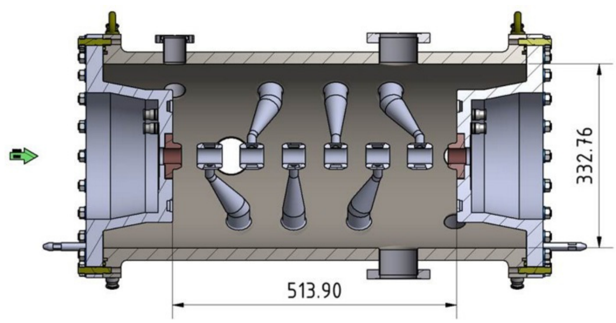

Figure 1: A 3D model for the high field prototype cavity.

Table 1: Main Parameters of the High Field CH – Cavity

Number of Gaps	7
Frequency (MHz)	325.224
Voltage Gain (MV)	6
Eff. Accel. Length (mm)	513.9
Average Eff. Accel. Field (MV/m)	13.3
Power Loss (MW)	1.76
Q_0 – value	12500
Effective Shunt Impedance (MΩ/m)	52.15
Aperture Diameter (mm)	27

The CH – cavity was built from stainless steel and was galvanically copper plated at its inner surface. Two processes with different bath ingredients (high lustre and less lustre copper plating) will be tested against each other at high rf power levels. The main aspect in our case is the sparking limit, besides quality factor, vacuum and rest gas aspects. The first round of copper plating (high lustre) was done at Galvano – T GmbH, Windeck, Germany (Fig. 2).

The drift tube structure was welded into a massive cylindrical tank. The stems with drift tubes are directly water cooled, the cylindrical tank has eight cooling channels in longitudinal direction. The electric and magnetic field distributions are shown in Fig. 3.

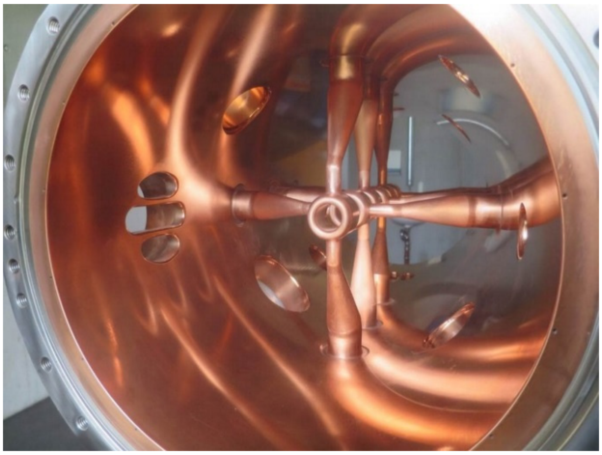

Figure 2: CH cylindrical tank after the copper plating.

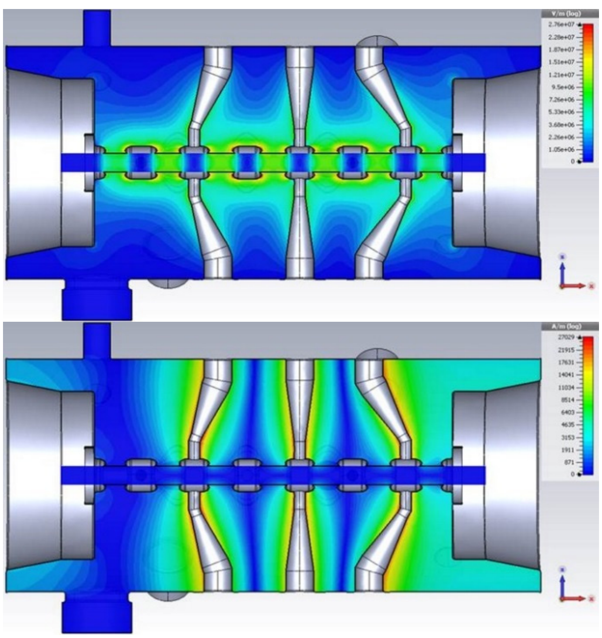

Figure 3: Electric (top) and magnetic (bottom) fields.

CAVITY MEASURMENTS

The cavity was successfully copper plated and returned back to IAP – Frankfurt. The resonance frequency, quality factor and field distribution were measured for this cavity.

Frequency

The resonance frequency of the CH – cavity can be reached by varying the magnetically acting tuner positions within the cavity.

For this cavity, the tuned resonance frequency is 325.224 MHz. In this case, three tuners were used: two fixed tuners and one movable tuner which allows for a frequency control in operation. Fig. 4 shows the tuner frequency shift versus the movable tuner positon.

The frequency and quality factor were measured and the results are shown in Fig. 5. Here the movable tuner should be at position 41 mm inside the cavity in order to reach 325.224 MHz. The quality factor value was 12400 ± 200.

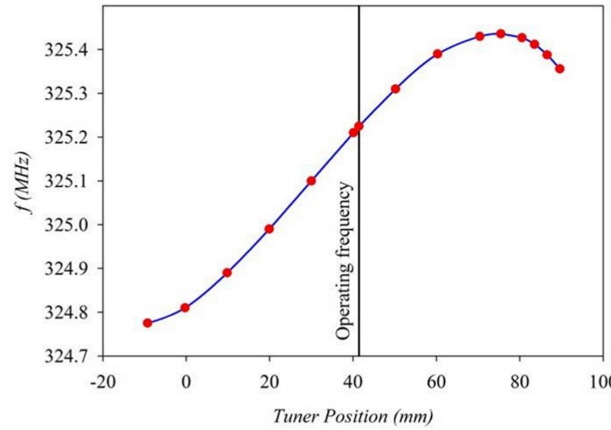

Figure 4: Tuner frequency shift of the movable tuner versus the tuner position.

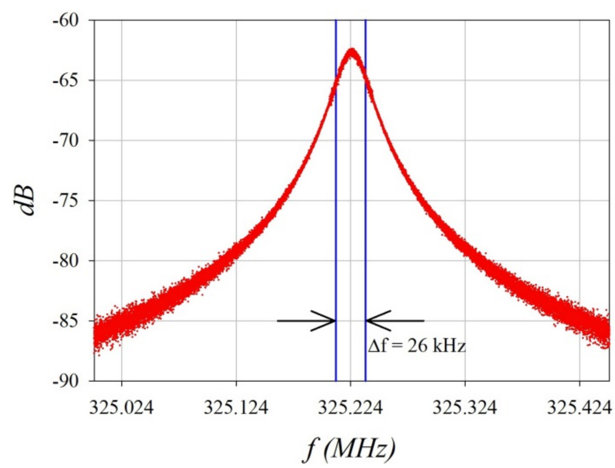

Figure 5: Resonance frequency and quality factor measurements.

On Axis Electric Field Measurement

The on axis electric field was measured versus the position using the standard bead – ball – perturbation technique. Fig. 6 shows the normalized on axis electric field of the cavity.

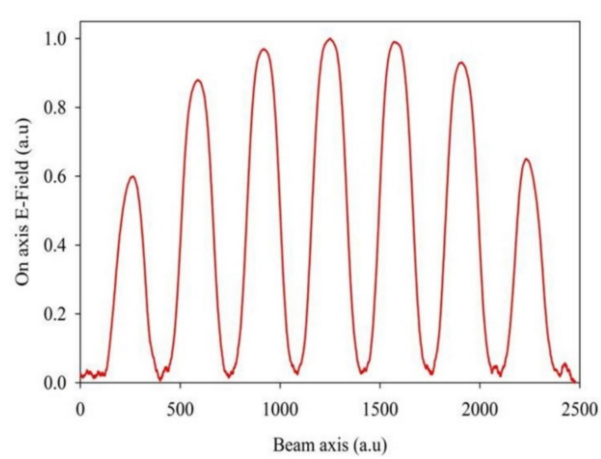

Figure 6: The measured on axis field.

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Such a shape was resulting in optimized effective shunt impedance, which is about 52.2 MΩ/m.

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. [7]. Unfortunately, the anomalous skin effect is reducing the advantage of rising conductivity as soon as the electron free path becomes as long as or even longer than the skin depth. At relatively low rf frequencies like in case of heavy ion structures and up to about 350 MHz there might be still 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.

The time averaged temperature increase caused by the rf wall losses at different operating temperatures is given for a fixed wall thickness for the two cavity materials stainless steel and copper in Table 2. This effect gives another limit for the acceptable duty factors.

Table 2: 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

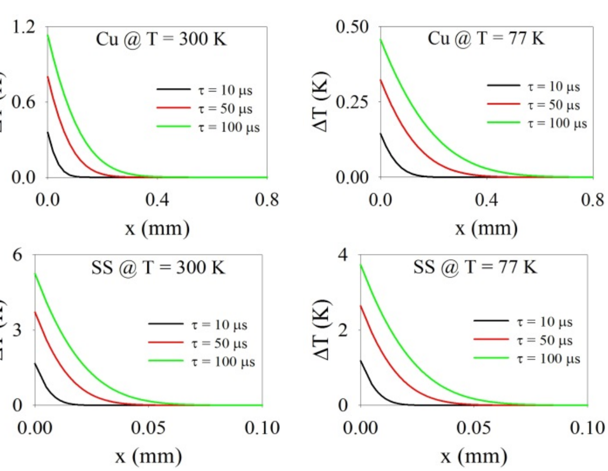

Fig. 7: Temperature profiles at the cavity surface at the end of specified pulse lengths.

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. [8].

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.

CONCLUSION

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

The measurements of resonance frequency and electric field distribution for the CH – cavity show a very good agreement with simulations.

The first round of copper plating (high lustre) has been finished and the cavity is ready for the high power RF test which can be performed at the GSI test stand driven by a 3 MW klystron. The main aspect in our case is the high sparking limit. The results from this test will be compared afterwards with cavity results from the second round of copper plating (less lustre).

The cavity operation at LN2 temperature seems promising at short pulse lengths < 100 µs and at low repetition rates of about 10 Hz. This option is still under investigation and is attractive for synchrotron injectors for example.

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