A 325 MHz HIGH GRADIENT CH – TEST CAVITY FOR β = 0.16*

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Abstract

This pulsed linac activity aims on compact designs, which means a considerable increase in voltage gain per meter. At IAP – Frankfurt, a CH – cavity was developed for these studies, where mean effective accelerating fields well above 10 MV/m are expected at 325 MHz, β=0.164. This cavity is developed within a funded project. Currently, the cavity is under construction and expected to be ready for copper plating in autumn 2014. The results might influence the rebuilt of the UNILAC – Alvarez section, which aims on achieving the beam intensities specified for the GSI – FAIR project. The new GSI 3 MW Thales klystron test stand will be very important for these investigations. Detailed investigations for two different types of copper plating can be performed on this cavity. In this work, the status of the cavity fabrication will be presented. Moreover, low temperature operation of copper cavities is discussed for the case of very short RF pulses.

INTRODUCTION

In conventional DTL's, the drift tubes will have a thick wall because of the need to house the focusing elements. Such geometries will cause bigger surfaces around the gaps, where the electric field levels are high. Thus, the stored field energies will be higher with an increased risk of spark damages on the surface. In addition, the multipacting probability will be increased which will also tends to reduce the save operation levels.

On the other hand, it was proved, that linac structures based on Interdigital – H – type structure (IH) allow reaching an effective field gain of about 10.7 MV/m at pulse length of 1 ms and at low beam energies [1].

H – Mode cavities are very well suited in that case, as they concentrate the electric field on the drift tube structure very well. Thus, the stored energy is reduced efficiently by a small outer drift tube diameter.

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 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 applications is needed. Also, for high current operation the high field acceleration provides the needed longitudinal focusing forces.

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.

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MECHANICAL DESIGN OF CH – CAVITY

At IAP – Frankfurt, a 7 – gap CH – cavity with constant β = 0.164 (Figure 1) is expected to have a field gradient of about 11.6 MV/m [3, 4]. This cavity is under construction at NTG GmbH and is expected to be ready for copper plating in autumn 2014.
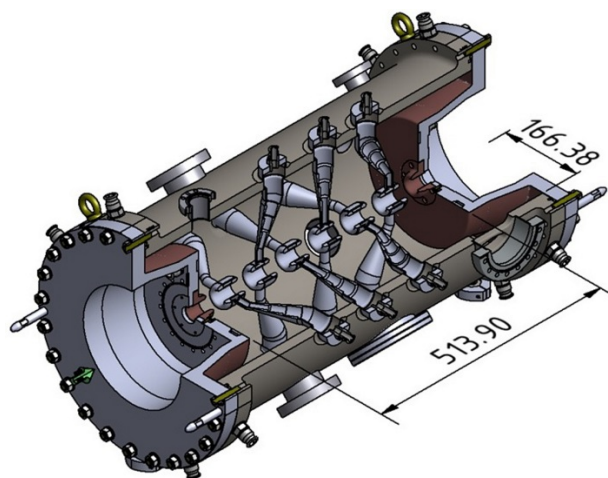

Figure 1: A 3D schematic view of the CH – cavity.

The on axis (path 1 in Figure 3) and towards the aperture radius shifted (path 2 in Figure 3) electric field distribution as calculated with MWS is shown in Figure 2. The corresponding gap voltage is expected to reach 1 MV for the plotted case.
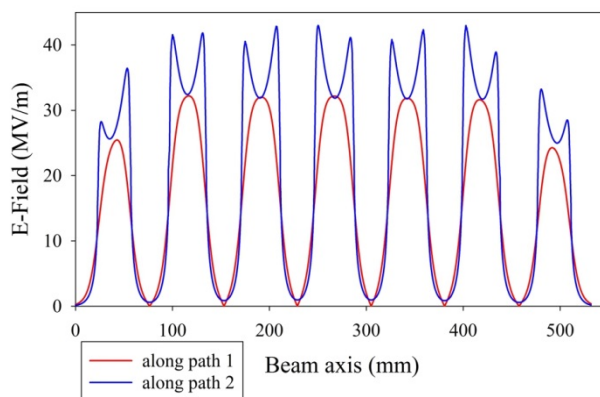

Figure 2: The axial electric field distribution as calculated by CST – MWS along the beam axis and along the aperture radius.

The main parameters of this cavity are given in table 1.

SURFACE ELECTRIC FIELD

The CH – DTL is designed with respect to KONUS – beam dynamics [2] where no internal focusing element is needed. Thus, the adaption of slim drift tubes is possible

(see Figure 3) and this results in a very high sparking limit.

Table 1: The 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)	11.6
Power Loss (MW)	1.76
Q_0 – value	12476
Effective Shunt impedance (MΩ/m)	52.15
Beam Aperture (mm)	27

The envisaged high effective field gradient of this cavity (11.6 MV/m) corresponds to local surface field spots of about 97 MV/m at the outer edges of the central drift tubes.
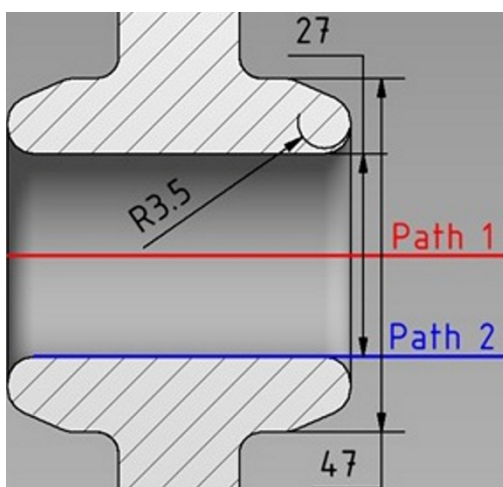

Figure 3: A cut of one of the drift tubes and the connection to the stems.

SURFACE PREPARATION

The CH – cavity will be built from stainless steel and will be galvanically copper plated its inner surface. This will be one challenge for such geometry, whereas the first copper plating results have been quite promising [2].

The cavity cylinder will contain no screwed connections. The end flanges are sealed by metal joints. Only the end half tubes are from massive copper.

The main goal is to find out the difference between high lustre copper plating which is used successfully at GSI – Darmstadt and the lustre less copper plating as applied successfully at some facilities recently.

The main aspect in our case is the high spark limit.

LINAC OPERATION AT LIQUID NITROGEN TEMPERATURE

In the CH – structures, the current flows from the outer cylinder radially to the drift tubes along the stems in order to generate the axial electric acceleration field.

The stems are giving the mechanical stability of the cavity and they carry the highest current density (see Figure 4).

The main power loss occurs along the stems. Because of that the stem design must be very robust and with efficient water cooling in case of higher duty factors.
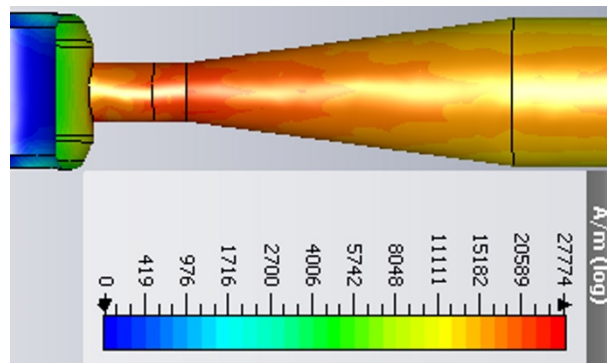

Figure 4: A detailed view on the surface current density along the stems. The stems are carrying the highest density near by the drift tubes due to the necessary low electric field capacity design.

The RF loss in copper is given by

$$P = \frac{1}{2} \int R_s \cdot H_0^2 \cdot dA \qquad (1)$$

where H_0 is the magnetic field amplitude and R_s is the surface resistance and is given by

$$R_s = \sqrt{\pi f \mu_0 \mu_r \rho} \qquad (2)$$

where f is the frequency, μ_0 is the magnetic permeability in vacuum, μ_r is the relative magnetic permeability of the conductor and ρ is the resistivity.

For a given frequency, R_s depends on the temperature through the resistivity dependence which is decreasing with temperature (see Figure 5).
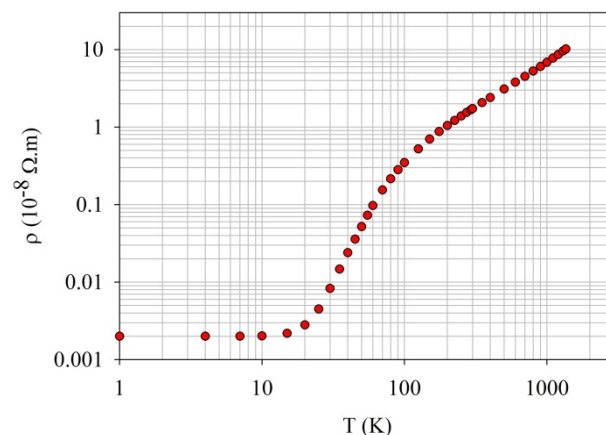

Figure 5: The copper resistivity as a function of temperature.

This means that the RF losses decrease when the copper is cooled down to lower temperature. This is true

down to about 70 K for copper at $325\,MHz$. Below this temperature, the anomalous skin effect [5] will play an increasing role and the RF losses do not follow $\sqrt{\rho}$ any more.

In the following, the cooling issues for the copper – cavity using liquid nitrogen LN2 will be addressed.

The power loss reduction factor at liquid nitrogen temperature (T = 77 K) against room temperature (300 K) is about 0.34 for copper.

For a pulsed exposure of the cavity surface to a constant heat flux P/A for $t > 0$, the temperature response of the surface at two different starting temperatures can be seen in Figure 6. For these studies, the heat flux of about 3.73 MW/m^2 was used in case of 300 K while it was about 1.26 MW/m^2 in case of 77 K (reduced power).

These results refer to a plane geometry of a semi-infinite solid [6], and this is the reason that, the surface temperature would increase indefinitely for $t \to \infty$.
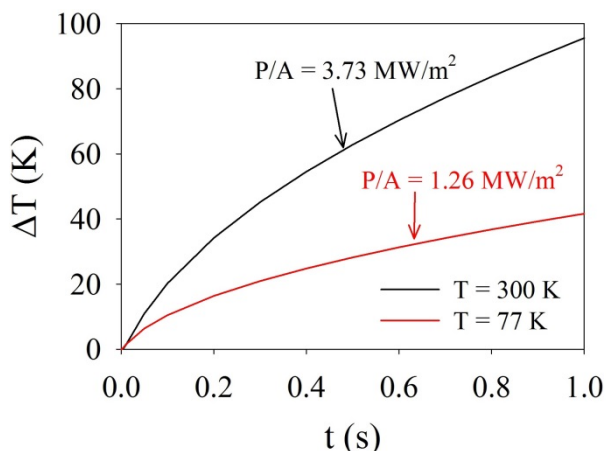

Figure 6: Surface temperature increase following a constant heat flux P/A at $t > 0$.

For short pulses as shown in Figure 7, the temperature profile depends additionally on the copper starting temperature (see Figure 7).
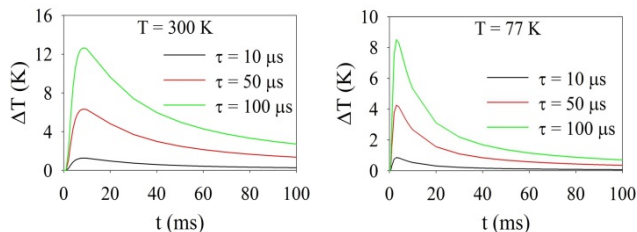

Figure 7: Surface temperature response of semi-infinite solids to an exposure of short pulses at T = 300 K (left) and T = 77 K (right).

A typical stem wall thickness is about 2 mm. Thus, it will be important to study the temperature response for a fixed pulse length versus the depth x (Figure 8). The results show that ΔT goes to zero within 0.8 mm in case of T = 77 K in copper.

The difference between two cases (T = 300 K and T = 77 K) is due to the dependence of the heat conductivity and the specific heat on temperature.

These results imply that the pulse length should be not significantly longer than $100\mu s$.

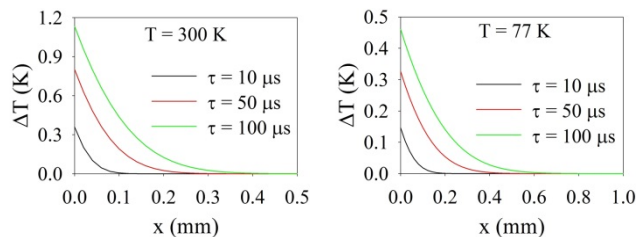Figure 8: Surface temperature profile response at T = 300 K (left) and T = 77 K (right).

CONCLUSION AND OUTLOOK

The development of a CH – cavity towards high field gradients has started. This aspect is important for low duty applications. There are many pulsed beam linac projects aiming on compact designs. One class of facilities are medical hospitals where available space is quite limited.

Another class might become ADS – facilities, if pulsed operation can be tolerated.

A new generation of 1 MW high power solid state amplifiers and H- type cavities may allow for a significant cost and size reduction of future ion linacs in the energy range up to about 100 AMeV.

Detailed investigations on the two different types of copper plating can be performed on this cavity and by using the GSI high power 325 MHz test stand driven by a 3 MW klystron.

The cavity operation at LN2 temperature seems promising at short pule lengths $< 100\mu s$ and at low repetition rates of about $10\,Hz$.

ACKNOWLEDGMENT

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