A REBUNCHING CH CAVITY FOR INTENSE PROTON BEAMS*

M. Schwarz†, C. Claessens, M. Heilmann, O. Hinrichs, D. Koser,
D. Mäder, O. Meusel, H. Podlech, U. Ratzinger, A. Seibel
IAP, Goethe-Universität Frankfurt am Main, Germany

Abstract

The Frankfurt Neutron Source at the Stern-Gerlach-Zentrum (FRANZ) will provide ultra-short neutron pulses at high intensities and repetition rates [1]. The facility is currently under construction at the Goethe-University in Frankfurt am Main (Germany).

A 5-gap CH rebuncher (see Table 1 and Fig. 3) is installed behind a coupled RFQ/IH-DTL combination at the end of the LINAC section between two magnetic quadrupole triplets (see Fig. 1). It will be used for varying the final proton energy around 2 MeV as well as for focusing the bunch longitudinally to compensate huge space charge forces at currents up to 200 mA at the final stage of extension.

High current beam dynamic simulations have been performed. They include benchmarking of different beam dynamic codes like LORASR [2] and TraceWin [3], as well as validating the results by measurements. Detailed examination of multipole field impact, due to the cavity's geometry, together with error tolerance studies and thermal simulations are also performed. Furthermore, this CH rebuncher serves as a prototype for rt CH cavities at MYRRHA (see Fig. 2), an Accelerator Driven System in Belgium for transmutation of high level nuclear waste [4]. After copper plating the cavity, RF conditioning will start soon.

In the following, the results regarding the electric quadrupole components will be presented.

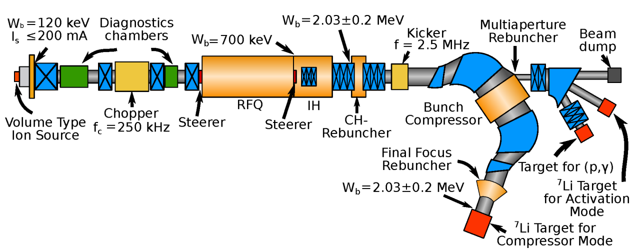

Figure 1: Schematic figure of FRANZ.

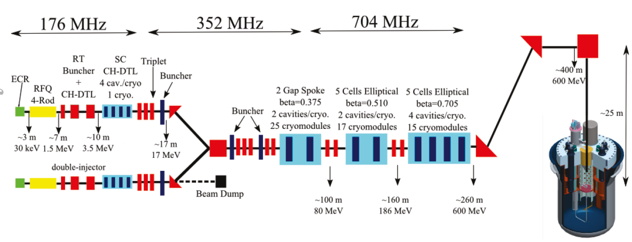

Figure 2: Schematic figure of the MYRRHA accelerator [5].

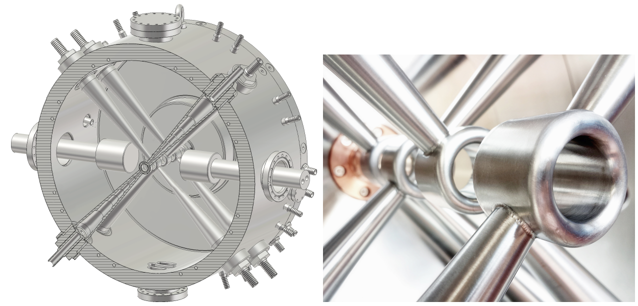

Figure 3: 3D model cross sectional view in CST MWS [6] *(left)* and picture of drift tubes and crossed stems *(right)*.

Table 1: Specifications of the CH Cavity

Parameter	Unit	Value
β		0.065
Frequency	MHz	175
Gaps	#	5
Total length	mm	462
Cavity inner diameter	mm	332
Aperture diameter	mm	24
Wall thickness	mm	40–52
Dynamic tuner	#	1
Static tuner	#	1
U	kV	295
U_{eff}	kV	245
Q_0 [1]		13500
Z_{eff} [1]	MΩ/m	58
P [1]	kW	2.9

MULTIPOLE COMPONENTS

The geometrical shape of CH structures with crossed neighbouring stems leads to a deformation of the electric fields inside the accelerating gaps. In addition to its dependence on the time t respectively the RF-phase φ_{RF}, the longitudinal position z and the distance to the beam axis r, the electric field varies with the azimuth angle φ: $\vec{E}(r, \varphi, z, t)$. The deviation of the colour contours from a circle to an elliptical geometry in Fig. 4 illustrates this asymmetry.

Former studies of drift tube linacs dealing with these asymmetries can be found for single- and multi-spoke cavities in [7]– [10] and for quarter-wave resonators in [11]. Initial studies on CH structures were published in [12] and [13]. In the following, the findings and results achieved so far will be further specified and extended, especially in relation to beam dynamics issues.

Figure 4 shows E_z along several straight lines parallel to the beam axis. When looking at the curves for $r = 11.9$ mm

* Work supported by the EU, FP7 MAX, Contract No. 269565
† schwarz@iap.uni-frankfurt.de
[1] simulated CST MWS value, normalized with the desired voltage.

Copyright © 2014 CC-BY-3.0 and by the respective authors

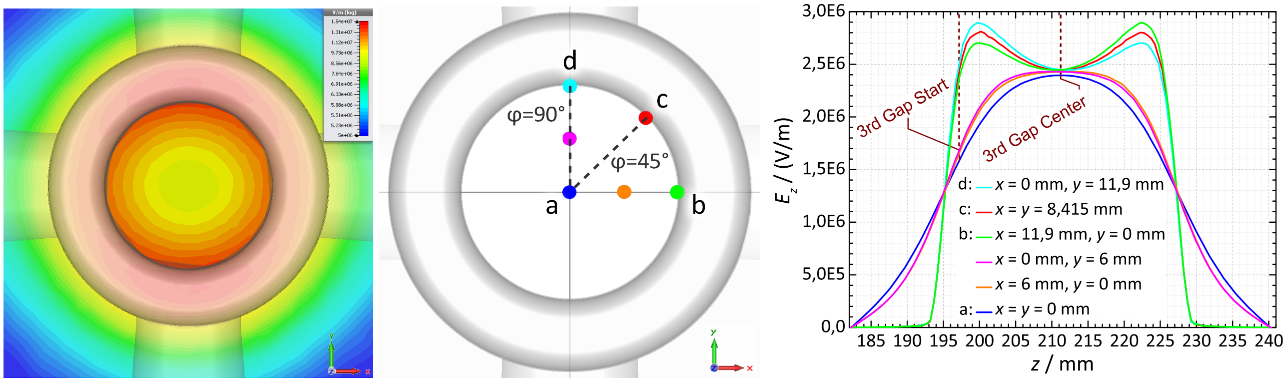

Figure 4: Logarithmic false-color plot of E_z in the 3rd gap *(left)*. Positions of straight lines for further analysis *(center)*. E_z along straight lines *(right)*.

a tilting of the local maxima in front of and behind the gap center at about $z = 211$ mm can be seen. A comparison of the resulting voltages shows differences:

$$U_{\mathrm{D3}\to\mathrm{D4,\,a}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{D4}}} E_{z,\,\mathrm{a}}\,\mathrm{d}z = 80.351\,\mathrm{kV} \quad (1)$$

$$U_{\mathrm{D3}\to\mathrm{D4,\,c}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{D4}}} E_{z,\,\mathrm{c}}\,\mathrm{d}z = 83.410\,\mathrm{kV} \quad (2)$$

$$U_{\mathrm{D3}\to\mathrm{D4,\,b}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{D4}}} E_{z,\,\mathrm{b}}\,\mathrm{d}z = 83.425\,\mathrm{kV} \quad (3)$$

$$U_{\mathrm{D3}\to\mathrm{D4,\,d}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{D4}}} E_{z,\,\mathrm{d}}\,\mathrm{d}z = 83.426\,\mathrm{kV} \quad (4)$$

$z_{\mathrm{D}n}$ stands for the center of the n-th drift tube. It is $z_{\mathrm{D3}} = 182.16$ mm and $z_{\mathrm{D4}} = 240.298$ mm. Neglecting transversal forces, a particle travelling on the beam axis undergoes with 80.351 kV a nearly 4 % lower accelerating voltage, than at the maximum aperture. Voltages up to the gap center at $z_{\mathrm{G3}} = 211.236$ mm are:

$$U_{\mathrm{D3}\to\mathrm{G3,\,b}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{G3}}} E_{z,\,\mathrm{b}}\,\mathrm{d}z = 40.833\,\mathrm{kV} \quad (5)$$

$$U_{\mathrm{D3}\to\mathrm{G3,\,d}} = \int_{z_{\mathrm{D3}}}^{z_{\mathrm{G3}}} E_{z,\,\mathrm{d}}\,\mathrm{d}z = 42.684\,\mathrm{kV} \quad (6)$$

The effect of azimuthal dependence becomes particularly apparent in this case. While on the one hand the total gap voltages for path (b) and (d) are nearly the same, the voltages up to the gap center differ quite more.

For further analysis, the E-field components on several circular paths around the beam axis have been evaluated (Fig. 6). Their radii are 50 % (6 mm) and about 99 % (11.9 mm) of the maximum beam aperture (12 mm). In z-direction they are positioned at the beginning of the gap, and at 10 %, 25 % and 50 % of the gap length. Figure 6 shows the longitudinal and radial E-field components in dependence of r, φ and z. A quadrupole modulation with the azimuth angle is clearly visible. The longitudinal E-field varies by up to ±4 %, the radial even by up to ±15 %.

In the gap center, E in dependence of φ is fairly uniform, compared to the other curves upstream. But another phenomenon appears: An octupole pattern (Fig. 7). This can be expected as an electrical octupole arises when two electrical quadrupoles are placed side by side but twisted by 90° to each other. The crossed stems inside the CH structure form these quadrupoles.

The amplitudes of the Fourier transformed E-field components are plotted in Fig. 7. $f = 2/2\pi r$ corresponds to a pure quadrupole (and clearly dominates the spectra), $f = 4/2\pi r$ to a pure octupole component. Higher frequencies can be traced back to numerical simulation errors.

BEAM DYNAMICS SIMULATIONS

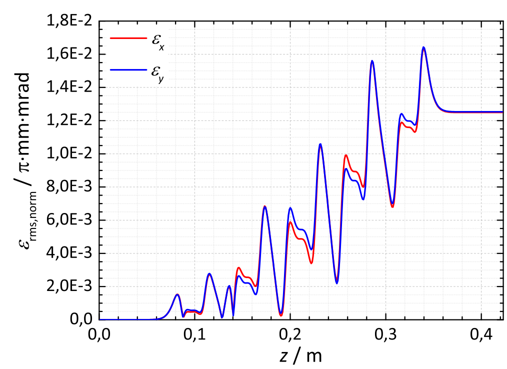

Figure 5: Emittance growth in x and y at $\varphi_{\mathrm{s}} = -90°$ with a pencil beam at $I = 0$ mA.

To determine the impact of the presented field asymmetries on a proton beam, beam dynamics simulations with TraceWin have been performed. It became apparent that the overall influence of these effects is very small, as modifications to the beam at the gap entrance are inverted when the beam exits the gap, due to the crossed stems. Nevertheless they can be made visible when using a “pencil beam” with extremely low emittance, which reacts very sensitive. By setting $\varphi_{\mathrm{s}} = -90°$ we ensure to have maximum transversal RF-defocussing inside the gaps and therefore the strongest influence of the electric quadrupole component.

Without multipole effects a congruent curve shape with respect to the emittance growth in both planes could be

Copyright © 2014 CC-BY-3.0 and by the respective authors

ISBN 978-3-95450-142-7

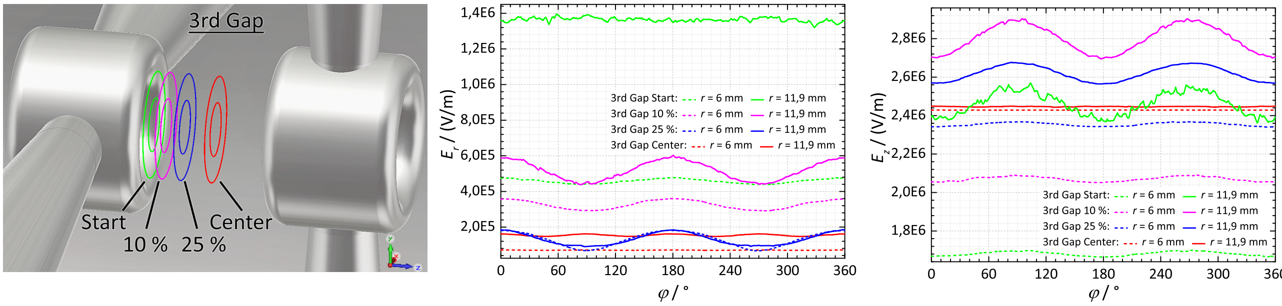

Figure 6: Circular paths to evaluate multipole components *(left)*. Radial *(center)* and longitudinal *(right)* *E*-field components along these paths.

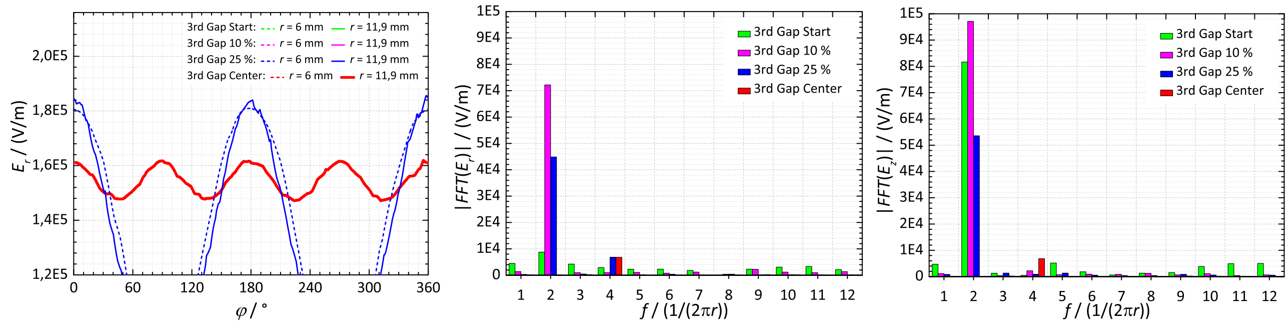

Figure 7: Detailed view for E_r at $r = 11.9$ mm with octupole structure *(left)*. Amplitudes of the Fourier transformed radial *(center)* and longitudinal *(right)* *E*-field components.

assumed. In contrast to this, Fig. 5 shows differences between *x*- and *y*-plane in all 5 gaps. The emittances differ partially by up to 15 %, but at the beam output only by about 0.3 %. At higher beam currents, space charge is the driving force for emittance growth and has a greater impact than the quadrupole effect. Nevertheless, further studies regarding longer accelerating structures and varying stem and drift tube geometry could yield interesting results.

ACKNOWLEDGMENT

The author would like to thank D. Uriot (CEA) for his support in using TraceWin.

REFERENCES

[1] C. Wiesner et al., "Chopping High-Intensity Ion Beams at FRANZ", WEIOB01, *These Proceedings*, LINAC'14, Geneva, Switzerland (2014), `http://www.JACoW.org`

[2] R. Tiede et al., "Improvements of the LORASR Code and Their Impact on Current Beam Dynamics Designs", TUPP063, *These Proceedings*, LINAC'14, Geneva, Switzerland (2014), `http://www.JACoW.org`

[3] D. Uriot et al.: `http://irfu.cea.fr/Sacm/logiciels/index3.php` last visit 10 August 2014

[4] D. Mäder et al., "R&D of the 17 MeV MYRRHA Injector", MOPP064, *These Proceedings*, LINAC'14, Geneva, Switzerland (2014), `http://www.JACoW.org`

[5] D. Vandeplassche et al., "Toward a Virtual Accelerator Control System for the MYRRHA Linac", MOPP064, IPAC'14, Dresden, Germany (2014), `http://www.JACoW.org`

[6] CST AG, Darmstadt, Germany: *MICROWAVE STUDIO®* `http://www.cst.com` last visit 10 August 2014

[7] J.-F. Ostiguy, N. Solya, "Residual Focusing Asymmetry in Superconducting Spoke Cavities", IPAC'11, San Sebastián, Spain, WEPS066 (2011), `http://www.JACoW.org`

[8] P. Berrutti et al., "Effects of the RF Field Asymmetry in SC Cavities of the Project X", IPAC'12, New Orleans, Louisiana, USA, WEPPC039 (2012), `http://www.JACoW.org`

[9] R. G. Olave et al., "Multipole Expansion of the Fields in Superconducting High-Velocity Spoke Cavities", LINAC'12, Tel-Aviv, Israel, MOPB072 (2012)

[10] C. S. Hopper et al., "Geometry Effects on Multipole Components and Beam Optics in High-Velocity Multi-Spoke Cavities", PAC'13, Pasadena, USA, WEPAC42 (2013), `http://www.JACoW.org`

[11] M. A. Fraser et al., "Compensation of Transverse Field Asymmetry in the High-Beta Quarter-Wave Resonator of the HIE-ISOLDE Linac at CERN", SRF'09, Berlin, Germany, TH-PPO026 (2009), `http://www.JACoW.org`

[12] H. Liebermann et al., "Coupler Development and Gap Field Analysis for the 352 MHz Superconducting CH-Cavity", LINAC'04, Lübeck, Germany, TUP86 (2004)

[13] G. Clemente et al., "Status of the 20 MeV, 20 mA CH Proton-DTL for FAIR", EPAC'06, Edinburgh, Scotland, TUPCH115 (2006), `http://www.JACoW.org`

Copyright © 2014 CC-BY-3.0 and by the respective authors