FABRICATION AND HIGH-GRADIENT TESTING OF AN ACCELERATING STRUCTURE MADE FROM MILLED HALVES

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Abstract

Accelerating structures made from parts which follow symmetry planes offer many potential advantages over traditional disk-based structures: more options for joining (from bonding to welding), following this more options for material state (heat treated or not) and potentially lower cost since structures can be made from fewer parts. An X-band structure made from milled halves, and with a standard benchmarked CLIC test structure design has been fabricated and high-gradient tested above 95 MV/m.

INTRODUCTION

The development of the high-gradient normal conducting accelerating structures has a strong influence on both performance and cost of the Compact Linear Collider (CLIC). As a consequence, significant effort has been invested in the optimization of the structures, while maintaining the CLIC performance requirements. The latter are defined by a loaded accelerating gradient of 100 MV/m, pulse length of around 200 ns and breakdown rate (BDR) of 10^{-7} 1/pulse/m [1].

The CLIC accelerating structures operate at 11.994 GHz and are made from copper. They are usually manufactured by precision turning and milling of individual cells, and combined with precision milling for complex parts such as RF power couplers. These multiple parts and auxiliary components such as cooling pipes, tuning pins and flanges are bonded into a complete structure [2]. An alternative approach is the use of precision milling to cut cells into metal blocks that comprise halves of the complete structure [3]. This novel accelerating structure design and assembly gives a number of advantages compared to traditional structures. In particular, reduction of the number of precision pieces per structure to two, free choice of joining since there are no RF currents flowing through the metal-to-metal joint and an overall reduction of the total fabrication and handling cost.

In this paper we describe the RF design, fabrication, tuning and high-power testing of a prototype accelerating structure, T24-open, milled out of two halves and brazed together (Fig. 1). It is a full tapered structure which includes 24 regular traveling wave cells and 2 matching cells and works at a $2\pi/3$ phase advance per cell. Each regular cell uses the same iris dimensions as the CLIC-G structure [4]. One of the main motivations for this work is to study the high gradient performance of accelerating structures made with novel manufacturing methods.

RF DESIGN

The RF design and optimization of the structure is described in [3]. The geometry is optimized to simplify the machining process, as well as to reduce the maximum surface electric and magnetic fields and the local modified Poynting vector (S_c) [5]. Therefore, a racetrack profile with 1 mm gap and an elliptical rounding of the irises is selected for the geometry of single cells. The commercial finite element code HFSS [6] was used for the simulations.

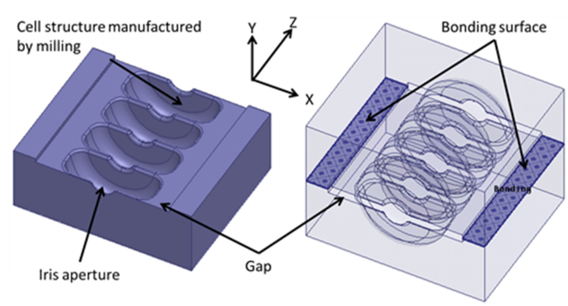

Figure 1: Manufacturing accelerating structure by milling on two halves of copper plate (HFSS model [6]).

The full tapered structure (Fig. 2) uses a so called waveguide coupler, with matching transitions to standard WR-90 waveguides. These are on-axis double-feed and can be manufactured by milling. The matching cell uses same geometry parameters as its neighbor regular cell except for the matching iris aperture. Dimensions are well tuned to minimize the reflection among the cells. The RF parameters of the full tapered structure are listed in Table 1 together with those of the CLIC-G undamped T24 structure.

STRUCTURE FABRICATION AND TUNING

The prototype T24-open structure, shown in Fig. 3, was machined at SLAC.

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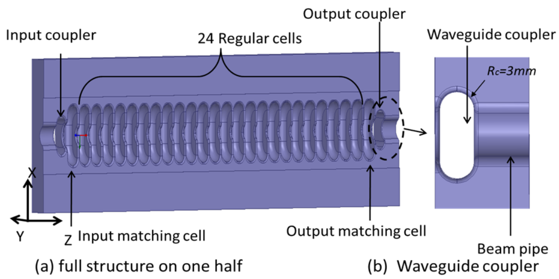

Figure 2: Model of the full tapered structure.

Table 1: RF Parameters of Full Tapered Structure

	T24-open	**CLIC-G T24**
Unloaded Gradient [MV/m]	100	100
Input/output radii [mm]	3.15/2.35	3.15/2.35
Group velocity [%c]	1.99/1.06	1.79/0.91
Shunt impedance [MΩ/m]	107/137	116/150
Peak input power [MW]	44.5	37.5
Filling time [ns]	49	57
Maximum E-field [MV/m]	268	222
Maximum Sc [MW/mm^2]	5.16	3.51
Maximum pulse heating temperature [K]	25	14

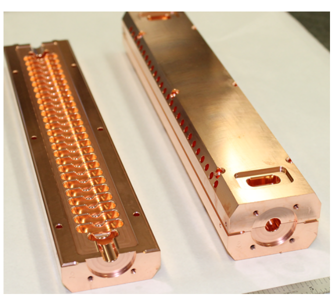

Figure 3: Structure and half structure prototype.

A pre-brazing RF test was performed to check the on-axis field profile and S-parameters. After the RF properties were verified, all parts received standard processing including polishing and Cu plating of the RF flanges, chemical cleaning, atmospheric pressure hydrogen brazing with Cu-Au alloys. The halves were cleaned with the standard SLAC procedure developed for the processing of high-gradient X-band accelerators with chemical etch time limited to 30 seconds. A more detailed description of the process can be found in reference [7]. After the structure was brazed, bead-pull measurements were carried out to determine the field profile along the structure. The results of the field pattern are presented in Fig. 4, while Fig. 5 shows the S-parameters before and after the tuning. The structure was successfully tuned, showing good field flatness and a cell to cell phase advance of 120 °±2 °. After tuning the structure was vacuum fired in an Ultra-High-Vacuum furnace at 550 °C for pressure asymptote at temperature, for more than 8 hours.

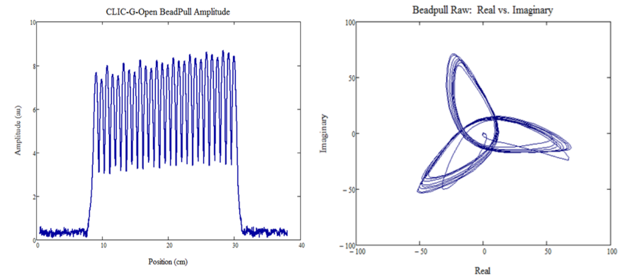

Figure 4: Bead-pull measurement results of the structure after tuning. Left: the on-axis field amplitude, right: polar plot of the bead-pull data.

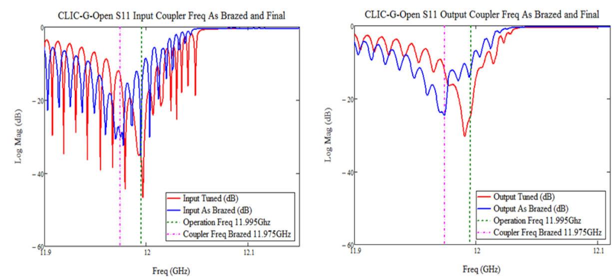

Figure 5: Input (left) and output (right) S-parameters of the brazed structure before (blue) and after (red) tuning.

HIGH-POWER-TESTING

The structure was shipped to CERN where it was installed in the Xbox-2 test stand (Fig. 6) in order to test its high-gradient performance. Xbox-2 is the second generation of the CLIC high-power klystron-powered test stand at CERN based on the same infrastructure design as in Xbox-1 [8]. Improvements include an upgraded control system, a more compact waveguide network and a new pulse compressor. This new pulse compressor can be fully detuned through the use of mechanical pistons. T24-open is the second structure that is tested in Xbox-2 after the crab cavity [9].

Figure 6: T24-open structure installed in Xbox-2.

The conditioning process followed that of the TD26CC at Xbox-1 in 2013 [10] and was computer controlled using the algorithm described in [8]. The structure history is summarized in Fig. 7. The power was ramped while maintaining a constant BDR of 3×10^{-5} bpp. An initial pulse width of 100 ns was used up to the gradient of 95 MV/m. Although, the structure was being well conditioned towards the target of 100 MV/m with a low and decreasing BDR (around 5×10^{-6} bpp), the operation was restricted by radiation interlocks due to bunker shielding issues. A pulse width of 155 ns was then chosen but the maximum reachable power was again limited by the radiation. Nevertheless, during that constant power run the BDR was decreasing, implying that the structure continued to condition. Finally, a pulse width of 200 ns was selected and different experiments at lower power were carried out [11] until the shielding problem was solved. Presently, the bunker shielding is enhanced and the conditioning towards the 100 MV/m is resumed. The change in the target power can be seen in Fig. 7 by the increase of the slope of the accumulated breakdowns.

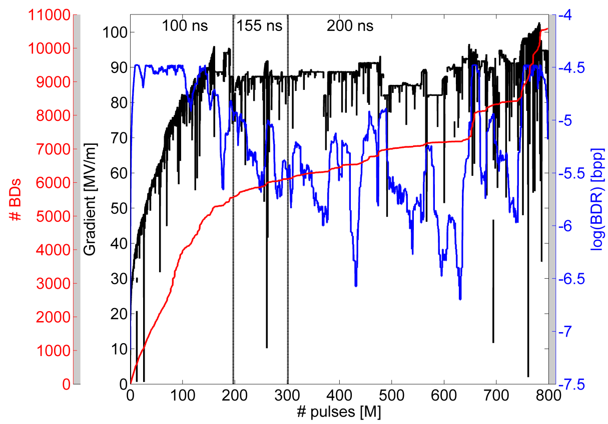

Figure 7: Summary of the T24-open test history.

The overall conditioning process of the T24-open is shown in Fig. 8, where the normalized modified Poynting vector is plotted together with different disk-based damped CLIC prototypes. The normalization was carried out using the empirical formula [5]:

$$BDR \propto S_c^{15}\tau^5, \tag{1}$$

where S_c is the modified Poynting vector and τ is the pulse width. There is a very good agreement between the different conditioning curves as expected from [5], meaning that the structure conditioned steadily throughout the run.

The detection and positioning of the RF breakdowns is done by acquiring the incident, transmitted and reflected RF signals, measured with RF directional couplers that are placed in the input and output of the structure. In addition, the signals of the Faraday cups upstream and downstream are also used to indicate the breakdown occurrence. Threshold detection on the reflected signal from the structure and the dark current signals are used to establish if a breakdown has occurred.

The position of each breakdown was determined using the timing of breakdown-induced features in incident, transmitted and reflected RF signals. The analysis followed is the same as the one presented in [12]. A histogram of the breakdown distribution inside the structure during the run of March 2016 is shown in Fig. 9. The edge method [12] was used where the position is calculated from the difference between the falling edge of the transmitted power (t_{TRA}) and the rising edge of the reflected power (t_{REF}). A slight excess of breakdowns is observed in the beginning of the structure but there is no evidence of the development of any 'hot' cell. The analysis is on-going.

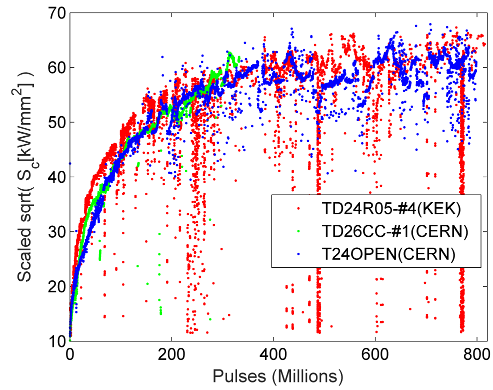

Figure 8: S_c normalized to τ=200 ns and BDR=10^{-6} bpp/m, for different accelerating structures. T24-open (blue color) is compared to different disk-based damped CLIC prototypes.

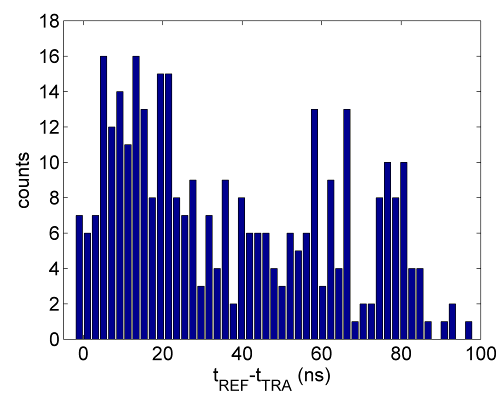

Figure 9: Breakdown distribution inside the structure during the run in March 2016 as a function of the time delay between the reflected and transmitted RF signals.

CONCLUSION

A novel CLIC prototype accelerating structure , T24-open, milled out of two halves and brazed together has been designed, successfully fabricated and tuned. Currently, T24-open is under high-power testing in the Xbox-2 test stand at CERN. The conditioning process of the structure is comparable with that of the disk-based CLIC prototypes. It reached an accelerating gradient of 95 MV/m with a relatively small BDR of around 5×10^{-6} bpp, but restricted by radiation interlocks due to bunker shielding issues. This problem is now fixed and the conditioning towards the 100 MV/m is resumed.

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REFERENCES

[1] M. Aicheler *et al.*, “A Multi-TeV Linear Collider Based on CLIC Technology,” CERN 2012-007.

[2] J. W. Wang, J. R. Lewandowski, J. W. Van Pelt, C. Yoneda, G. Riddone, *et al.*, “Fabrication technologies of the high gradient accelerator structures at 100 MV/m range,” in *Proc. IPAC’10*, Kyoto, Japan, 2010.

[3] V. Dolgashev, A. Grudiev, and H. Zha, “RF Design of the CLIC structure prototype optimized for manufacturing from two halves,” in *Proc. IPAC’15*, Richmond, USA,2015.

[4] A. Grudiev and W. Wuensch, “Design of the CLIC main linac accelerating structure for CLIC Conceptual Design Report,” in *Proc. LINAC’10*, Tsukuba, Japan, 2010.

[5] A. Grudiev, S. Calatroni, and W. Wuensch, “New Local Field Quantity Describing the High Gradient Limit of Accelerating Structures,” *Phys. Rev. ST Accel. Beams* 12, 102001 (2009).

[6] Ansys HFSS, `http://www.ansys.com`

[7] V. Dolgashev *et al.*, “Building open traveling wave accelerating structures,” talk on HG2015, Beijing, China, 2015.

[8] N. Catalan-Lasheras *et al.*, “Experiences Operating an X-Band High-Power Test Stand at CERN,” in *Proc. IPAC’14*, Dresden, Ger-many, 2014.

[9] B. Woolley *et al.*, “High gradient testing of an X-band crab cavity at XBOX2,” in *Proc. IPAC’15*, Richmond, USA, 2015.

[10] A. Degiovanni *et al.*, “High-gradient test results from a CLIC prototype accelerating structure: TD26CC,” in *Proc. IPAC’14*, Dresden, Germany, 2014.

[11] T. Argyropoulos and J. Giner-Navarro, “High-power test of a structure built from halves,” talk on HG2016, Argonne, USA, 2016.

[12] A. Degiovanni *et al.*, “Diagnostics and analysis techniques for high power X-band accelerating structures,” in *Proc. LINAC’14*, Geneva, Switzerland, 2014.