



HIGH POWER TESTS OF A PROTOTYPE X-BAND ACCELERATING STRUCTURE FOR CLIC

Riccardo Zennaro², Heinrich Blumer², Markus Bopp², Terence Garvey², Leonid Rivkin², Nuria Catalan-Lasheras¹, Alexej Grudiev¹, Gerard McMonagle¹, Anastasiya Solodko¹, Igor Syratchev¹, Rolf Wegner¹, Benjamin Woolley¹, Walter Wuensch¹, Thomas Lucas³, Matteo Volpi³, Theodoros Argyropoulos⁴, Daniel Esperante-Pereira⁴

¹CERN, Geneva, Switzerland

²Paul Scherrer Institut, Switzerland

³University of Melbourne, Australia

⁴University of Valencia, Spain

Abstract

We present the design, construction and high-power test of an X-band radio-frequency accelerating structure, built as a prototype for the CERN LInear Collider (CLIC) study. X-band structures have been attracting increasing attention in recent years with applications foreseen in the domains of compact free electron lasers, medical accelerators and as diagnostics for ultra-short (femtosecond) electron bunches (when used in deflecting mode). To date, the main motivation for developments in this field has been as accelerating structures for linear colliders such as CLIC. In the context of a CERN/PSI collaboration we have built a prototype structure based on an existing CERN design, but with some modification, and following, as closely as possible, the realization and vacuum brazing techniques employed in the production of the C-band structures for the Swiss Free Electron Laser, SwissFEL. We will present the basic design of the structure and describe the fabrication process. The results of high power conditioning of the structure at CERN on an X-box test stand, to assess conditioning times, accelerating field and measure breakdown rates, will also be presented.

8th International Particle Accelerator Conference, Copenhagen, Denmark, 14 - 19 May 2017

Geneva, Switzerland

18 May 2017

HIGH POWER TESTS OF A PROTOTYPE X-BAND ACCELERATING STRUCTURE FOR CLIC*

R. Zennaro, H. Blumer, M. Bopp, T. Garvey, L. Rivkin,
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

N. Catalan-Lasheras, A. Grudiev, G. McMonagle, A. Solodko, I. Syratchev, R. Wegner,
B. Woolley, W. Wuensch, CERN, Geneva, Switzerland

T. G. Lucas, M. Volpi, University of Melbourne, Australia

T. Argyropoulos, D. Esperante-Pereira, University of Valencia, Spain

Abstract

We present the design, construction and high-power test of an X-band radio-frequency accelerating structure, built as a prototype for the CERN LInear Collider (CLIC) study. X-band structures have been attracting increasing attention in recent years with applications foreseen in the domains of compact free electron lasers, medical accelerators and as diagnostics for ultra-short (femtosecond) electron bunches (when used in deflecting mode). To date, the main motivation for developments in this field has been as accelerating structures for linear colliders such as CLIC. In the context of a CERN/PSI collaboration we have built a prototype structure based on an existing CERN design, but with some modification, and following, as closely as possible, the realization and vacuum brazing techniques employed in the production of the C-band structures for the Swiss Free Electron Laser, SwissFEL. We will present the basic design of the structure and describe the fabrication process. The results of high power conditioning of the structure at CERN on an X-box test stand, to assess conditioning times, accelerating field and measure breakdown rates, will also be presented.

INTRODUCTION

The production of 120 C-band accelerating structures for SwissFEL provided PSI with the opportunity to develop a strong expertise in the field of travelling wave structures [1]. Although the nominal gradient for SwissFEL is 28.5 MV/m, the PSI recipe for structure production may be of interest also for high gradient performance. During high power test a two-meter long C-band structure reached gradients exceeding 50 MV/m [2]. These results together with the “tuning free” technology developed at PSI made it interesting, for high gradient studies, to produce two X-band T24 prototypes using this technique. T24 is one of the most well tested designs for CLIC and it is the ideal candidate for a comparative study on performance [3]. These test structures also allow us to compare the vacuum brazed technology applied by PSI to the diffusion bonding, which is presently used by CERN for the CLIC structures [4, 5].

STRUCTURE PRODUCTION

The mechanical design is very similar to that of the SwissFEL C-band structure, with the main difference being the input/output couplers which are of the mode launcher type as for many CLIC test prototypes. All cups and the two couplers were produced by the company VDL [6]. The inner profiles of the cups are all well within the specified tolerances ($\pm 2 \mu\text{m}$) and the average surface roughness (R_a) is below 20 nm. The cups have been vacuum fired at 400 °C for two hours before brazing in order to remove residual oxidation. The cooling circuits are integrated in the cups whose external diameter was reduced from 110 mm to 90 mm because of the different RF frequency. Because of this modification the pre-brazing stacking was not possible with the robot employed for SwissFEL structures. Instead manual stacking was employed. The stacking is based on a pre-heating ($\Delta T=50$ °C) shrink-fit design. The final straightness after brazing is better than 10 microns. The RF design had to be slightly modified to adapt it to the PSI mechanical design which is based on copper disks with one half cell machined on each side in order to have the brazing plane in the middle of the cell as shown in Figure 1.

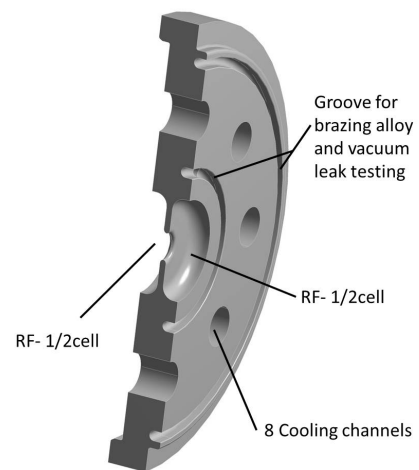


Figure 1: View of a section of one cell.

This solution allows one to have double rounding of the cells and to prevent the braze alloy from flowing into the structure through capillary action. This design is possible thanks to the absence of any tuning feature. The double

rounding allows also a larger Q factor of the cells. The basic parameters of T24 PSI prototype are shown in Table 1. Two brazing gaps house the copper-silver brazing wire. Sharp edges in the cells stop the melted brazing material from flowing into the cells and the size of the brazing gap has been experimentally optimised to provide the best reproducibility of the brazing material distribution. Air channels allow one to check for vacuum tightness after brazing.

Table 1: Cavity Parameters

Frequency (GHz)	11.9944
Number of accelerating cells	24(2)
Phase advance/cell (°)	120
Iris aperture diameter $a_{in,out}$ (mm)	6.30,4.70
Iris thickness $t_{in,out}$ (mm)	1.67, 1.00
Group velocity $v_{g,in,out}$ (%c)	1.8, 0.9
Quality factor $Q_{in,out}$	7250, 7615
Filling time (ns)	59
Input power for 100 MV/m (MW)	37.5

LOW POWER MEASUREMENTS

Bead pulling and S-parameters measurements were performed at CERN. The structure, as shown in Figure 2, was mounted vertically and the nylon wire for the bead pulling was inserted from the top without risk of touching the irises. During measurements the structure was constantly under dry nitrogen flow.

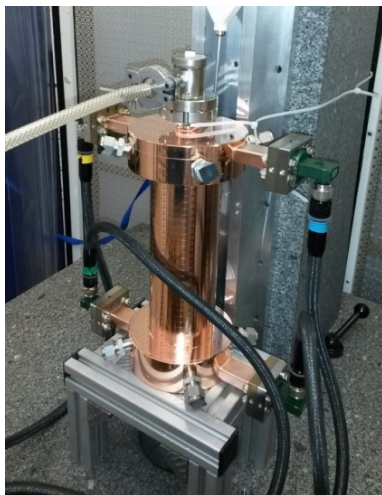


Figure 2: Structure ready for vertical bead-pulling.

Given that the structure does not have any possibility of tuning it was vital to fabricate it at the exact operating frequency. The input match shown in Figure 3 is -31 dB. The operating temperature is 35.5 °C, 2.5 °C more than the design value (33 °C). The field along the structure, as shown in Figure 4 has a small standing wave component, probably due to a mismatch of the last two cells.

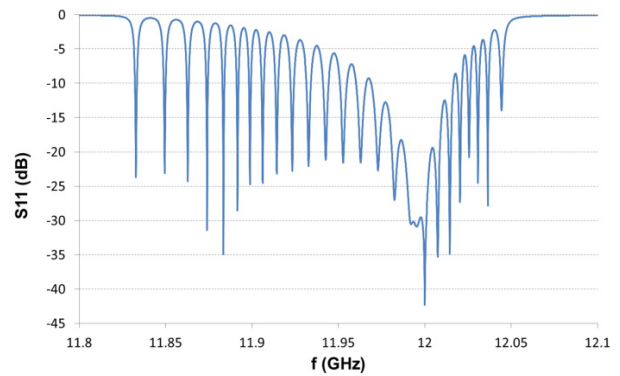


Figure 3: Reflected power to the input, S11 is equivalent to -31 dB at the equivalent working frequency in vacuum (11.9944 GHz).

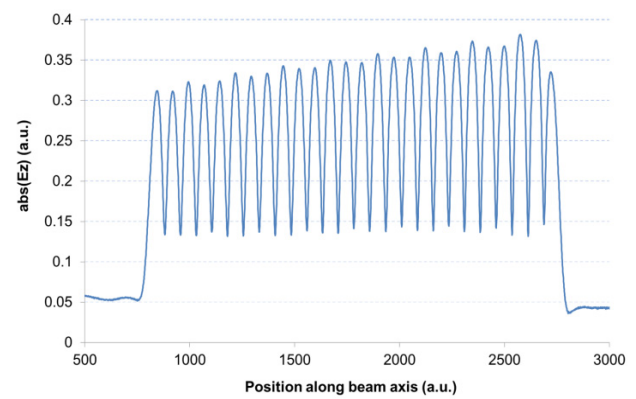


Figure 4: Bead pulling results: electric field on axis (arbitrary scale) along the structure, input on the left.

HIGH POWER MEASUREMENTS

Following the low power testing, the structure was installed on one of the test slots CERN's most recent X-band test stand, XBOX3 (Figure 5) [7-9].

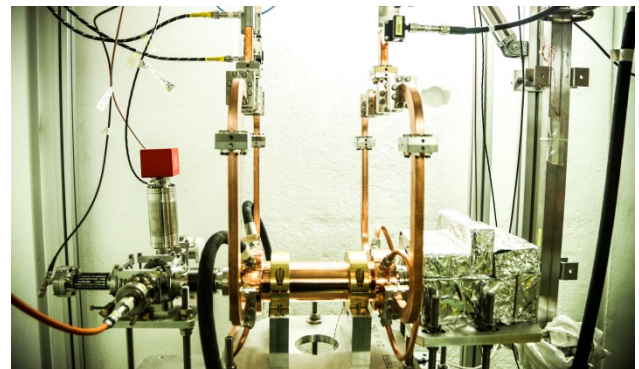


Figure 5: Structure installed in XBOX3.

XBOX3 is a unique development in X-band testing capabilities with two 6 MW Toshiba klystrons [10] combined to create the pulse to feed the SLED pulse compressor. The relatively low peak power klystrons allow for higher repetition rates, up to 400 Hz, which allows the T24 PSI manufactured structure to be tested at 100 and 150 Hz at various stage of conditioning. This compares to

the standard 50 Hz testing of previous test stands Xbox 1 and 2. Similar to past structures, the structure's conditioning was algorithmically set to keep a constant BDR of $5 \cdot 10^{-5}$ bpp (breakdowns per pulse) while varying the input power accordingly. Figure 6 demonstrates the structure conditioning history to date, scaled to the CLIC nominal operating parameters (10^{-6} BDR with 200 ns pulse length) using standard scaling low [11]. The structure has run continuously for three weeks, or approximately 180 million pulses, and reached 100 MV/m average gradient at the first pulse length of 60 ns pulse. A comparison to a previously conditioned TD26CCR05 structure demonstrates the similarity in the conditioning of the structure to a standard bonded structure.

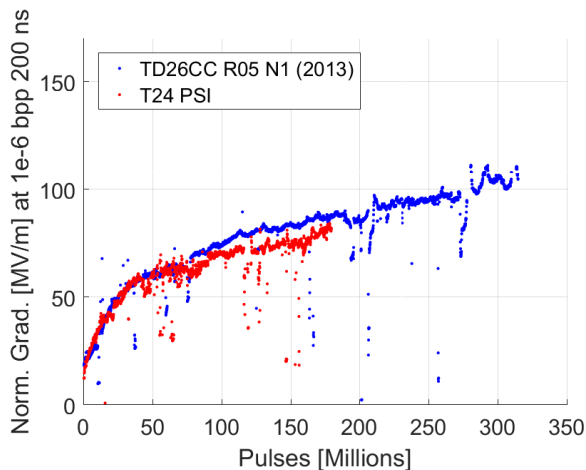


Figure 6: Structure conditioning history.

Quantifying the quality of the surface of the structure is done through a power scan measuring the dark current level on a radiation monitor. The field enhancement factor β , in the Fowler Nordheim Equation [12] is obtained by a simple linear fitting as shown in Figure 7.

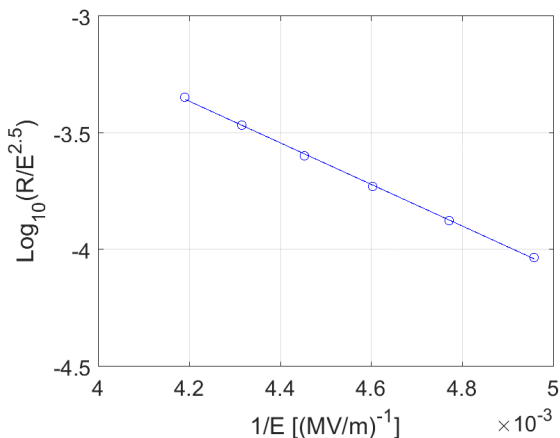


Figure 7: Linear fit of the Fowler Nordheim; R (Radiation) is proportional to the dark current.

The measured β value is 31 and is consistent with previous bonded structures demonstrating the high surface quality achieved in fabrication.

CONCLUSION

Developments in vacuum brazing at PSI for SwissFEL have led to a whole new structure production technique. Based on the T24 CLIC structure design, PSI designed and fabricated a new brazed structure for the high gradient application of CLIC. Initial conditioning has demonstrated the new structure performance with comparable results to previous structure produced through standard bonding. After twelve days of testing the structure has reached the 100 MV/m average gradient and is currently running at 150 ns pulse length.

REFERENCES

- [1] J.-Y. Raguin, M. Bopp, A. Citterio, and A. Scherer, "The SwissFEL C-band accelerating structure: RF design and thermal analysis", in *Proc. LINAC'12*, Tel-Aviv, Israel, Sep. 2012, pp. 442-444.
- [2] R. Zennaro, J. Alex, A. Citterio, and J.-Y. Raguin, "Measurements and high power test of the first C-band accelerating structure for SwissFEL", in *Proc. LINAC'14*, Geneva, Switzerland, Aug.-Sep. 2014, pp. 333-335.
- [3] R. Zennaro *et al.*, "Design and fabrication of CLIC test structures", in *Proc. LINAC'08*, Victoria, BC, Canada, 2008, pp. 533-535.
- [4] A. Solodko *et al.*, "Novel manufacturing concepts for 12 GHz high gradient accelerating structures", presented at IPAC'17, Copenhagen, Denmark, paper THPAB039, this conference.
- [5] A. Xydou *et al.*, "Production of CLIC accelerating structures using diffusion bonding at very high temperature", *Int. Journal of Metallurgical and Materials Science and Engineering (IJMMSE)*; vol. 6, no. 2, Apr. 2016.
- [6] <http://www.vd1groep.com>
- [7] N. Catalan Lasheras *et al.*, "Commissioning of XBOX3: a very high capacity X-band RF test stand", in *Proc. LINAC'16*, East-Lansing, MI, USA, Sep. 2016, pp. 569-572.
- [8] A. Degiovanni *et al.*, "Comparison of the conditioning of high gradient accelerating structures", *Phys. Rev. Accel. Beams*, vol. 19, p. 032001, 2016.
- [9] B.J. Woolley *et al.*, "High power x-band generation using multiple klystrons and pulse compression", presented at IPAC'17, Copenhagen, Denmark, paper THPIK095, this conference.
- [10] <http://www.toshiba-tetd.co.jp/eng/tech/klystron.htm>
- [11] A. Grudiev, S. Calatroni, and W. Wuensch, *Phys. Rev. ST Accel. Beams*, vol. 12, p. 102001, 2009.
- [12] R.H. Fowler and L. Nordheim, *Proc. Royal Society A*; vol. 119, p. 173, London, UK, 1928.