



Technological Advancements in Material Handling for High-Gradient Operation of

an innovative braze-free accelerating structures

V.A. Dolgashev¹, L. Faillace², B. Spataro² and R. Bonifazi³

Abstract

High energy physics experiments using particle accelerators as well as industrial and medical applications are continuously seeking more compact, robust and cheaper accelerating structures. As of today, stable operating gradients, exceeding 100 MV/m, have been demonstrated by the SLAC group in the X-Band (11.424 GHz). These experiments show that hard structures, fabricated without high-temperature processes, achieve a better high gradient performance in terms of accelerating gradients. Therefore, we present an innovative and compact type of accelerating cavity that avoids any high-temperature processes like brazing or diffusion bonding. All cells are joined together by means of specifically designed and proprietary screws which ensure good vacuum and RF contacts. Two three-cell standing-wave accelerating structures, designed to operate in the pi-mode at 11.424 GHz, have been successfully built and cold tested. In order to guarantee a vacuum envelope and mechanically robust assembly, we used the Electron Beam Welding (EBW) and the Tungsten Inert Gas (TIG) processes. This work has been carried out in the framework of a funded project by the Vth Committee of the INFN for the Laboratori Nazionali di Frascati (LNF), within a large international collaboration between LNF, SLAC and KEK for the development of X-Band accelerating cavities using "hard structure" technology. A preliminary temperature and stress tests during the welding process is shown. The high power RF tests have been performed at SLAC by achieving excellent results.

Introduction

- There is a strong demand for accelerating structures able to achieve higher gradients and more compact footprints for the next generation of linear accelerators [1], for research, industrial and medical applications [2, 3]. The project presented herein is the result of a continuous, decade-long collaboration involving SLAC in the U.S.A and KEK in Japan.
- Accelerating cavities are usually made of many single cells bonded together. The most common bonding techniques, used worldwide, are high-temperature brazing and diffusion bonding. The brazing and the diffusion bonding are performed inside a high-temperature furnace. The first process involves the melting of copper alloys which bond together the metallic surfaces of adjacent cells. In the second one, the melting occurs directly at the contact surfaces.



- These high-temperature processes require high-level skills and are often unsuccessful in the production of cavities suitable for high RF power operation, as it is well-known in the accelerator community. Many are the risks of both brazing and diffusion bonding which could lead to either a failure of the process itself or damage to the structure or both. For example, if the brazing alloy is not properly placed, small pockets with air can remain around the filler regions causing virtual leaks [4] which are sources of trapped gas into the ultra-high vacuum volume or if the furnace has a vacuum issue it can cause the structure inside to oxidize.
- Another reason to avoid the high-temperature bonding processes is the possibility to achieve higher accelerating gradients with hard un-annealed copper-alloy structures. Recent experiments [3, 5] have demonstrated that structures made out of hard copper alloys can achieve higher accelerating gradients with lower RF breakdown rates (BDR) with respect to the high-temperature treated ones.
- Furthermore, the brazing or diffusion bonding costs are also an issue since dedicated fixture, filler materials and furnace time, just to mention a few, need to be accounted for. The improvement in high gradient performance and the cost of high-temperature bonding led us to the invention proposed in this paper.
- In this paper, we show the design and mechanical tests of an innovative cost-effective 3-cell accelerating X-band cavity realized without using the high-temperature bonding processes. The accelerating structure, made out of hard copper material, will be consequently employed for high-gradient tests as well as the study of the physics of RF breakdown.
- The structures were successfully high power tested at SLAC. RF high power tests were successful results.

Solid model, one-half of the braze-free 3-cell cavity: 1. High-gradient cells, RF vacuum chamber; 2. Special screws for clamping; 3. Input RF flange 4. secondary vacuum chamber; 5. Vacuum flange for the secondary vacuum chamber; 6. Downstream vacuum flange; 7. Water cooling pipe.

In figure above, it is shown the solid model of the 3-cell accelerating X-band structure, that we call the "Squeeze cavity", showing our proposed clamping system which is achieved by means of special and proprietary screws (2). Thanks to this innovative approach, it is possible to obtain perfect RF contacts between the cells and the desired quality factor without using any high-temperature bonding process. Two vacuum regions or chambers are present in the structure. The primary RF vacuum chamber (1) is the volume inside the high-gradient accelerating cells, where the RF power builds up the electromagnetic field. This chamber is connected to a vacuum pump through the input circular RF flange and the circular downstream vacuum flange (3 and 6). The secondary vacuum chamber (4) serves two important purposes: 1) it prevents any virtual air pockets, created between cells clamped together, from leaking gas into the primary vacuum chamber; 2) it reduces the risk of contamination of the primary chamber caused by the welding process performed on the outer surfaces of the cavity.



- Avoids high temperature processes
- Cells joined together by means of specifically designed and proprietary screws which ensure good vacuum and RF contacts
- Use the Electron beam welding (EBW) and Tungsten Inert gas (TIG) processes
- Remarkable improvements of the RF performance and Strong costs

Tungsten Inert Gas (TIG) welding process VS. **Electron Beam Welding (EBW) process**



Setup prototype for Temperature Monitoring during TIG Welding





(a) Left: the copper structure before the TIG process showing the machined teeth used to localize the heat produced by the welding process; right: the thermocouples wired and attached to the cell to monitor the temperature during the TIG process. (b) The temperature plots of the three thermocouples during one TIG test. In this case the tooth thickness is 0.9 mm and the peak electric current 160 A. Welding time was about 1.2 minutes [7].

reductions

• Strong increase of the accelerating field $E_{acc} > 100 \text{ MV/m}$

Left, 3-cell cavity after TIG welding. Right, 3-cell cavity after electron beam welding. 1. Welding joints; 2. Input RF flange; 3 Downstream vacuum flange; 4. Circular flange for pumping the secondary vacuum chamber. In figure above, we show the two cavity prototypes after welding with the EBW and TIG techniques. Geometrically, the primary vacuum envelope in both structures are identical Each cell is individually connected to the other by means of stainless steel screws that hold them tightly together. They both have a primary RF vacuum chamber, i.e. the volume where the electromagnetic field will resonate, and a secondary vacuum chamber, while they differ in the welding procedures. The welding joints are also shown [6].

- Tooth thickness is proportional to welding current: lower current, smaller tooth
- Ideal compromise: lowest current, mechanically more stable welding (robustness) and vacuum tightness

High power experimental tests

- Structure was successfully constructed and high power tested which validates the TIG welding approach toward building full scale multi-cell low cost linacs.
- Slope of the breakdown rate vs. gradient is steeper then soft copper structures and close to that of CuAg structures.
- Neither gradient or peak pulse service heating are good predictors of the breakdown rate which is not surprising for hard-copper structure.



Conclusions

- We have proposed here an innovative approach for cell-tocell clamping, by means of special custom screws, which avoids high-temperature brazing or diffusion bonding. The choice for working with hard structures which are not high temperature treated is justified by decade-long studies performed in National Labs world-wide (e.g. SLAC, KEK) that showed a better high-gradient performance with respect to high-temperature treated cavities.
- The first two prototypes were vacuum tight and tested at low RF power. The clamping mechanics permits to obtain ultra-high vacuum level (< 1E-12 Torr), sufficient for high-gradient operation. We decided, for these first two prototypes, to proceed to the welding of the outer surfaces of the cavity by using the EBW and TIG processes, in order to assure a steady vacuum envelope and more robust mechanical assembly.
- The primary purpose of this project is a study of high gradient performance of structures joined in a novel way using special screws. By creating a secondary vacuum chamber and welding the structure to seal the vacuum envelope, we created a robust way to ensure vacuum integrity. The study of feasibility of clamped-only structure will be done in the next steps, once the high gradient performance of the current two structures is verified.

References

[1] M. Ferrario et al., "EuPRAXIA@ $SPARC_LAB$ Design study towards a compact FEL facility at LNF", submitted Nucl. Instrum. Meth. (2018) [arXiv:1801.08717].

(b)

- [2] 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 (2009) 102001.
- [3] V.A. Dolgashev, S.G. Tantawi, A.D. Yeremian, Y. Higashi and B. Spataro, "Status of high power tests of normal conducting single-cell standing wave structures", in Proceedings of the IPAC 2010, Kyoto, Japan, 23-28 May 2010, pp. 3810-3812 (and references therein).
- [4] https://www.mtm-inc.com/av-20100312-vacuumchamber-design-what-is-a-virtual-leak.html.
- [5] V.A. Dolgashev, "High Gradient, X-Band and above, Metallic RF structures", talk given at the 2nd European Advanced Accelerator Concepts Workshop, La Biodola, Isola d'Elba, Italy, 13-19 September 2015.
- [6] Dolgashev, V. A., et al. "Innovative compact braze-free accelerating cavity. "Journal of Instrumentation 13.09 (2018): P09017.
- [7] V.A. Dolgashev, L. Faillace, A. Marcelli, B. Spataro and R. Bonifazi, "Materials vs. technological processes: new results from mechanical tests of an innovative braze-free accelerating cavity ", forthcoming paper.
- [8] V.Dolgahev, "Building and High Power Testing Welded









workshop, June 10-14,2019, Chamonix (FR)

