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**NOVEL MANUFACTURING CONCEPTS FOR 12 GHZ HIGH GRADIENT  
ACCELERATING STRUCTURES**

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**Abstract**

CLIC high gradient accelerating structures (AS) working in X-band are made of copper ultra-high precision discs, requiring both milling and turning operations. Discs are then joint together by diffusion bonding. The rest of important technical systems, such as vacuum, cooling and manifolds, to house damping silicon carbide absorbers, are brazed to the bonded disc stack afterwards. This manufacturing technique has been successfully demonstrated but it is very challenging and needs an accurate assembly at every production step. Main issues concern vacuum-tightness, misalignment, deformations during different assembly operations, defects of brazing/bonding operations (gaps, a leak of brazing material) etc. Preparation and repairs are time and resource consuming and increase the final price of the accelerating structure. This paper describes the novel manufacturing concepts for 12 GHz high gradient AS and focuses on new joining techniques as electron beam welding or brazing, new engineering solutions, as rectangular cells or structures made of halves are being considered.

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# NOVEL MANUFACTURING CONCEPTS FOR 12 GHz HIGH GRADIENT ACCELERATING STRUCTURES

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## Abstract

CLIC high gradient accelerating structures (AS) working in X-band are made of copper ultra-high precision discs, requiring both milling and turning operations. Discs are then joint together by diffusion bonding. The rest of important technical systems, such as vacuum, cooling and manifolds, to house damping silicon carbide absorbers, are brazed to the bonded disc stack afterwards. This manufacturing technique has been successfully demonstrated but it is very challenging and needs an accurate assembly at every production step. Main issues concern vacuum-tightness, misalignment, deformations during different assembly operations, defects of brazing/bonding operations (gaps, a leak of brazing material) etc. Preparation and repairs are time and resource consuming and increase the final price of the accelerating structure. This paper describes the novel manufacturing concepts for 12 GHz high gradient AS and focuses on new joining techniques as electron beam welding or brazing, new engineering solutions, as rectangular cells or structures made of halves are being considered.

## INTRODUCTION

The baseline design of prototypes for CLIC [1] is based on experience of an international collaboration between CERN, SLAC and KEK on high gradient X-band AS development. The AS body is formed by OFE copper discs joined by diffusion bonding at about 1040°C (see Fig. 1).

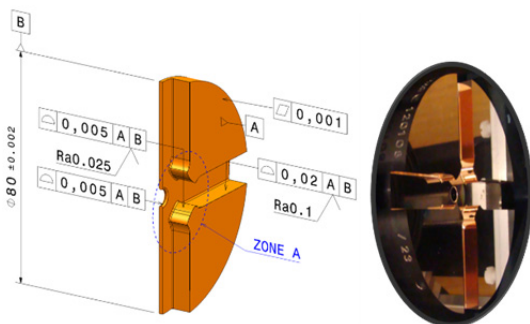


Figure 1: Technical drawing for a regular copper cell with open damping waveguides.

The shape accuracy of the cells is demanding ( $\pm 2 \mu\text{m}$ ). Each disc includes four waveguides to provide strong suppression of High Order Modes (HOMs). The geometry, as well as dimensions and tolerances of each disc are based on the RF performance of the full tapered structure whose main parameters can be seen in Table 1.

As shown in Fig. 2, each cell is prolonged by channels machined in external vacuum manifolds. A vacuum tight

contact with the bonded disc stack is provided by brazing. Four vacuum manifolds are brazed directly onto the AS body by means of a thin foil of brazing alloy. Small RF absorbers made out of SiC [1] are fixed inside the manifolds in order to efficiently suppress the transverse wake-fields.

Table 1: Structure Parameters

Average loaded accelerating gradient	100 MV/m
Frequency	12 GHz
RF phase advance per cell	$2\pi/3$ rad
Number of regular cells	26
Structure length including couplers	230 mm
Input/output iris radii	3.15/2.35 mm
Peak input power	61.3 MW
Maximum surface electric field	230 MV/m
Maximum pulsed surface heating temperature rise	47 K

The cooling system is integrated into the vacuum manifolds in order to provide a more compact technical solution. Manifolds are also equipped with vacuum flanges for pumping the structure.

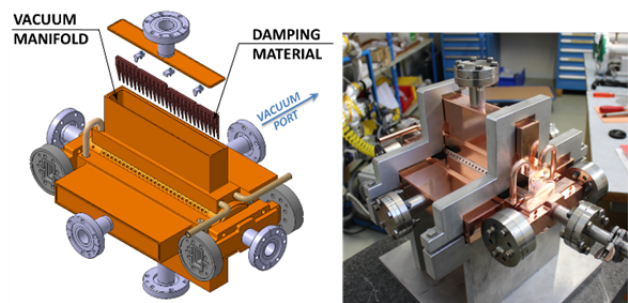


Figure 2: 3D section view of AS with SiC absorbers.

## ALTERNATIVE ENGINEERING SOLUTIONS

The AS body formed by ultra-high precision copper discs has been retained as baseline solution. The current production method of discs is based on a longitudinally-asymmetrical shape, where one side of the disc contains the RF cell and the other side is flat with the exception of the iris.

The vacuum manifolds and the discs are also ultra-high precision parts. Joining the manifolds to the body has proven to be a complicated operation with a high risk of vacuum leaks and very tight constraints. In order to find more robust technical solution in terms of precision, ma-

chining and assembly time and price, a few different production concepts are being investigated in parallel.

*Integrated Version Disc*

Two different configurations of cells were studied: a rectangular shape and a bigger diameter. The RF design and following mechanical design were done in such a way as to allow to integrate SiC absorbers, pumping features and cooling into the cell body.

The first attempt was focused on the feasibility of machining and bonding cells of a larger diameter (see Fig.3). Since the disc is bigger (220 mm compared to the baseline solution of 80 mm disc), achieving the required shape accuracy, surface flatness and roughness needed to be proven. Also, the quality of the bonding joint in a larger surface needed to be investigated. Production of the disc rose several questions, such as deformation during manufacturing steps due to big surface and small thickness (saddle shape), need of new tooling for machining and metrology (using a vacuum chuck instead of free state measurement), new bonding tooling, which has to combine both weight and compactness etc.

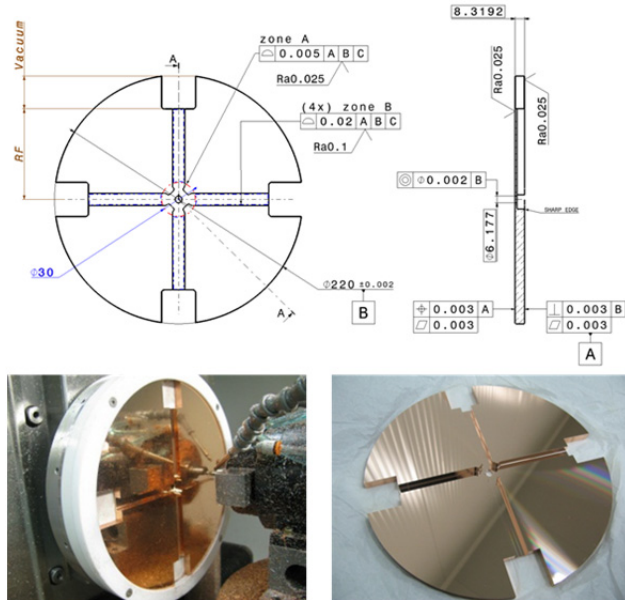


Figure 3: Manufacturing of 220 mm discs.

Two companies were able to produce seven prototype cells fulfilling the specification: shape accuracy about 5  $\mu$ m, the flatness of 2  $\mu$ m and 5  $\mu$ m and the roughness of 12 nm, measured in clamped position by a vacuum chuck.

The next step will be to carry out a bonding test.

*Rectangular Cell*

In the meantime it has been proposed to modify the cell geometry, to make it more compact and decrease the bonding surface, therefore a rectangular cell (see Fig. 4) was considered as an alternative [2].

The main difference with the baseline design is the position of waveguides. In the rectangular version they are parallel to each other which helps to optimise the overall geometry of the cell and consequently the dimensions of the AS.

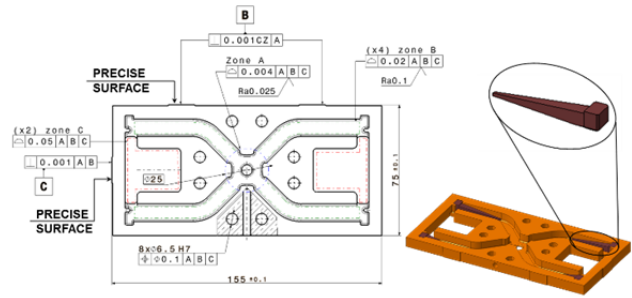


Figure 4: Rectangular cell.

The alignment features are also different. While the ultra-precise external diameter (cylindrical surface) aligns the copper discs, in the rectangular cell it is done by three ultra-precise lateral reference surfaces. In both configurations a 1  $\mu$ m flat bonding surface is required.

The design allows to minimise the number of parts and joining heating cycles. The first test set up is also equipped with HOM loads which are housed in the waveguides with a minimum positive allowance.

To prove the concept, a bonding test including SiC absorbers is under preparation, with consequent leak tightness tests of the cavity and cooling circuits. Three prototype cells and corresponding accessories are under production.

*Halves*

Manufacturing the structure from halves is also being studied as an alternative production method. The idea is to form the AS body by joining two copper halves.

Comparing to the copper disc, halves are manufactured using only ultra-precise milling operation which will increase the number of potential providers. Some deformations as a “saddle” effect presented in the copper discs with open damping waveguides will also be suppressed.

A significant advantage of a structure made from milled halves is a reduced number of parts and as a result, the number of assembly steps. But the longitudinal alignment becomes one of the most critical issues. A positioning error accumulates with every next cell whereas in the structure made of discs it differs from cell to cell.

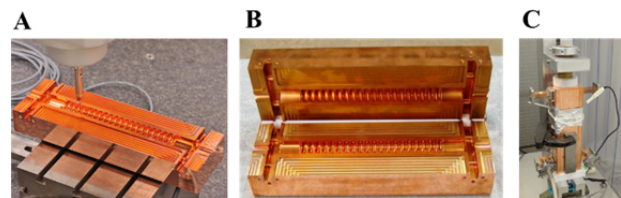


Figure 5: T24 structure in halves; a) metrology, b) two halves, c) bead-pull measurements before bonding.

The first prototype was designed and built at CERN (see Fig. 5). The bead-pull measurements of the prototype halves before bonding showed that the structure was good even without tuning. The structure was bonded and metrology results showed a gap of 10 to 200  $\mu$ m and a shift between irises up to 70  $\mu$ m. It opened the questions on reviewing of the alignment method, engineering design and joining method.



The second prototype of structures in halves was designed based on the special RF design of the undamped structure T24-OPEN [3] including special features for brazing. Parts were machined and assembled at SLAC [4]. AS was successfully tested under high-power in the Xbox-2 test stand at CERN [5]. Test results proved the concept and showed good performance of half made structures.

The RF design of the second prototype includes the 1 mm gap between the two halves which minimizes fields at the brazing or bonding joint located at the side of the gap. This feature lowers requirements for bonding, brazing and allows to consider electron beam welding (EBW) as an alternative soldering technique.

The next RF design for the halves-made structure corresponds to the CLIC needs and implements a strong damped design.

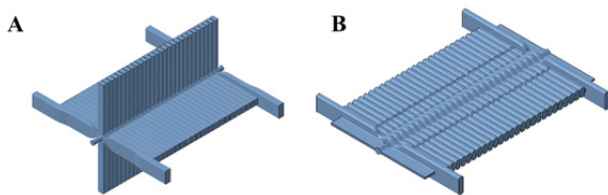


Figure 6: Internal volume of the structure; a) baseline TD26 CC [1], b) CLIC-HDS-A [6].

A new CLIC Half made Damped Structure (HDS) [6] includes HOM suppression. Engineering design of the first HDS prototype to be joint by EBW is under finalisation.

## ALTERNATIVE JOINING METHODES

### Electron Beam Welding

One of the interesting advantages of EBW technique is it offers the possibility to build an AS made of hard copper, without high temperature heating cycles as bonding or brazing. In comparison with a screwed or clamped version EBW ensures the vacuum tightness of the assembly. Based on the RF design shown in Fig. 6, a 3D view of the first HDS prototype fully EB-welded is shown in Fig. 7.

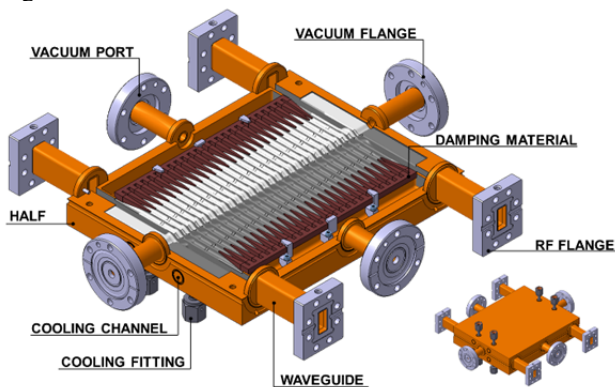


Figure 7: 3D view of HDS for EBW.

A test set up is built to check the feasibility of new joining solution, especially for the high-power performance. Two WR90 waveguides and two halves welded together

just form a continuing WR90 waveguide cross section (see Fig. 8).

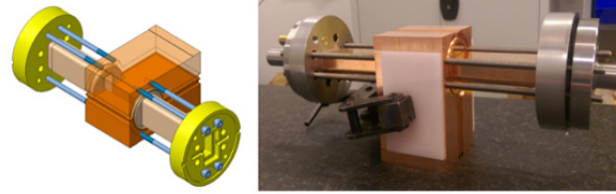


Figure 8: Test set up for EBW.

### Brazing

Assembly by brazing was already considered several years ago for the first prototypes of x-band structures. But it was decided to take advantage of the high-gradient work of NLC/JLC [7] while concentrating on the RF design. Now that the RF design has been proven at high gradient, and with a baseline production procedure, cheaper alternatives are being investigated. The brazing concept as a reliable joining method has been successfully shown recently first at PSI with the SwissFEL project and then at SLAC with the already mentioned AS made from halves.

Two T24 structures have been built at PSI based on the SwissFEL assembly procedure using high temperature brazing under vacuum [8]. They will be tested in the Xbox-3 test stand at CERN in the coming months.

## CONCLUSIONS

The high gradient accelerating structures working in X-band require ultra-precise milling and turning operation and very accurate assembly steps afterwards. The baseline design and assembly procedure has been established during long time. But taking into account fast developing of industries and technologies novel manufacturing concepts are considered for aspects of the structure production and for overall cost reduction.

Alternative production methods, currently being validated, have been presented. Several accompanying tests are conducting to prove the present concepts.

## REFERENCES

- [1] A. Grudiev, W. Wuensch, "Design of the CLIC main linac accelerating structure for CLIC conceptual design report", in *Proc. LINAC10*, Tsukuba, Japan, September 2010, paper MOP068, pp. 211-213.
- [2] H. Zha, A. Grudiev "New CLIC-G structure design", Geneva, Switzerland, CLIC - Note - 1066, May 2016.
- [3] H. Zha, A. Grudiev, V. Dolgashev "RF design of the CLIC structure prototype optimized for manufacturing from two halves", in *Proc. IPAC2015*, Richmond, USA, May 2015, paper TUPTY054, pp. 2147-2149.
- [4] V. Dolgashev et al., "Building open traveling wave accelerating structures," presented at HG2015, Beijing, China, June 2015, unpublished.

- [5] N. Catalan Lasheras et al., « Fabrication and High-gradient testing of an accelerating structure made from milled halves”. in *Proc. LINAC 16*, Michigan, USA, September 2016, paper THPLR003, pp. 804-807.
- [6] H. Zha, A. Grudiev, “Design of the Compact Linear Collider main linac accelerating structure made from two halves”, *Phy. Rev. ST Accel. Beams 20*, p° 042001, 2016.
- [7] K. Takata, “Overview of NLC/JLC collaboration”, in *Proc. LINAC2002*, Gyeongju, Korea, August 2002, paper TU102, pp. 254-258.
- [8] R. Zennaro, “Production of C-band cavities and pulse compressor for SwissFEL,” presented at HG2015, Beijing, China, June 2015, unpublished.  
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