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.
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 (± 2 µm). 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 wakefields.

Table 1: Structure Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average loaded accelerating gradient</td>
<td>100 MV/m</td>
</tr>
<tr>
<td>Frequency</td>
<td>12 GHz</td>
</tr>
<tr>
<td>RF phase advance per cell</td>
<td>2π/3 rad</td>
</tr>
<tr>
<td>Number of regular cells</td>
<td>26</td>
</tr>
<tr>
<td>Structure length including couplers</td>
<td>230 mm</td>
</tr>
<tr>
<td>Input/output iris radii</td>
<td>3.15/2.35 mm</td>
</tr>
<tr>
<td>Peak input power</td>
<td>61.3 MW</td>
</tr>
<tr>
<td>Maximum surface electric field</td>
<td>230 MV/m</td>
</tr>
<tr>
<td>Maximum pulsed surface heating temperature rise</td>
<td>47 K</td>
</tr>
</tbody>
</table>

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.

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-

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

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 µm 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 supressed.

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 3: Manufacturing of 220 mm discs.

Two companies were able to produce seven prototype cells fulfilling the specification: shape accuracy about 5 µm, the flatness of 2 µm and 5 µm 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 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 µm and a shift between irises up to 70 µm. It opened the questions on reviewing of the alignment method, engineering design and joining method.

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

**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.

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 X-box-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 being 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**


