PRODUCTION AND QUALITY CONTROL OF THE FIRST MODULES OF IFMIF-EVEDA RFQ

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Abstract

The IFMIF/EVEDA RFQ, designed to accelerate a 125mA D+ beam from 0.1 MeV to 5 MeV at a frequency of 175 MHz, consists of 18 modules with length of ~550 mm each. The production of the modules has been started and 2 prototype modules plus module 16 have undergone all the production steps, including precision milling and brazing. The progress of the construction and especially the fine tuning of the design and engineering phase are reported.

BRAZING PROCEDURE MODIFICATIONS

Once completed the 2 steps brazing of the 1st module prototype, the acquisition of a continuous active scanning measuring machine (Zeiss Accura) allowed a deep and extensive investigation of the internal geometry of the cavity. A wide series of transversal and longitudinal scanning were then performed. The more detailed and reliable measurements showed a lack of symmetry induced by gravitation effect during the 1st step brazing [1]. The final geometry of the cavity resulted still within the acceptable tolerances range for a single module, but not for the complete line, figures 1 and 2. A vertical brazing assembly, which permitted instead a possibility of a single brazing step, has been developed, figure 3. In this respect, the groove geometry, layout and tooling had to be redesigned. We introduced extensive US scanning (destructive test) and inspection (non-destructive) for the qualification of the brazed surfaces (Cu-Cu and Cu-st. steel).

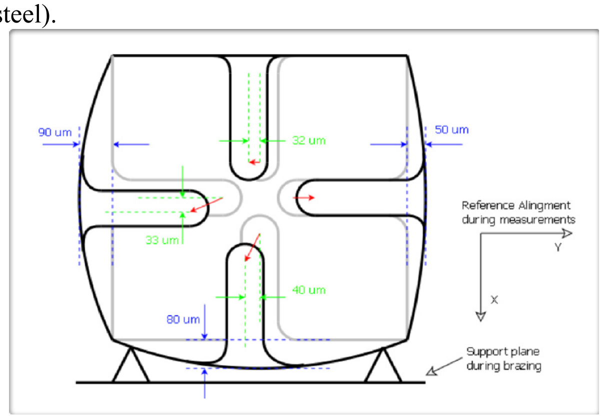
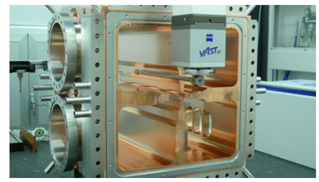


Figure 1: Scheme of the deformation of the cavity of the module 1 prototype after the second brazing



Pole	ΔX	ΔY	ΔR_0
	[μm]	[μm]	[μm]
1	-40	-80	89.44
2	50	0	50.00
3	-32	0	32.00
4	-90	-33	95.86
	mean ΔR_0	**[μm]**	**66.83**
	$\partial f/\partial R_0$	[kHz/ μm]	7.60
	Δf	**[kHz]**	**507.87**

Figure 2: Module 1 prototype during CMM survey (left) and displacements of the tips (right).

R & D FOR SINGLE BRAZING STEP

With a single brazing step, the number of thermal cycles, reducing the mechanical properties of copper (1 annealing step + 1 final brazing step), is minimized.

The overall precision of the final geometry is optimized.

The cost and the timing of the modules production are also optimized.

Some basic tests on specimens having the same groove design, in order to compare vertical to horizontal brazing, have been performed.

Then two almost full scale tests have been performed finalizing an updated tooling set.

A complete inspection by US scan on slices of the brazed surfaces has been done (destructive). The grooves result always completely empty and no significant voids were detected on the brazing planes, figure 4.

Following these results, the production of the final modules started with SuperModule III-HE section. We adopted the vertical brazing approach but still with 2 brazing steps, until all details were well stated.

We completed the production of the module 16 (April ’12), the second prototype module (July ’12) and the 1st brazing step of module 17 (July ’12).

The 1st single brazing step will be adopted on module 15 by October ‘12.

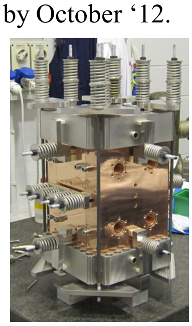


Figure 3: Full scale single brazing test

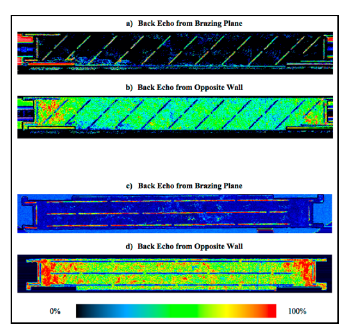


Figure 4: US inspection of two different brazing grooves design

THE MODULE 16'S PRODUCTION

The Quality Assurance of the Mechanical Machining

The continuous feedback between the mechanical machining and the measurement results was essential to guarantee the tight design tolerances.

The continuous active scanning survey of the tip geometry is mandatory to check the real geometry with adequate accuracy. The traditional point to point survey measurement (standard approach on CMM's) was attempted, but it failed.

The effectiveness of the active scanning control was essential to adjust and refine the CAM programs and the tooling fine tuning.

A standard procedure for the accurate control of each machining step of all the components and of the assembled module has been established:

- survey and qualification of each component, figure 5 and 6;
- survey and qualification of the dry-assembly of the module before the machining of the common reference planes;
- survey and qualification of the module after each brazing step;
- survey and qualification of the final module compared with the RF measurement.

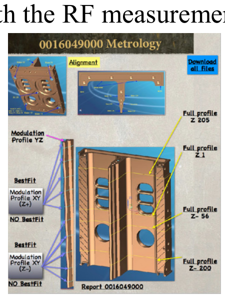


Figure 5: Inspected elements for the qualification of each CuC2 component of the cavity

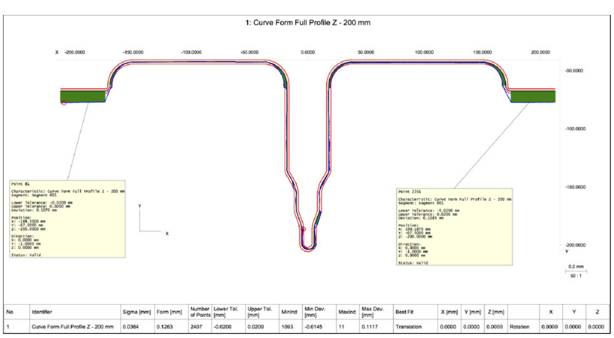


Figure 6: Example of measure of a profile by means active continuous scanning.

The Brazing Procedure, Module Dry Assembly

All the components are aligned to the nominal position and double checked, geometrically and RF.

The assembly is then machined to refine the common planes for the placement of the brazing tooling, figure 7.

The components are then dismantled, chemically cleaned, reassembled in a clean environment by means of the tooling, figure 8.

In this step the 2 sealing st. steel front rings have been mounted in order to provide a relevant constraint, embedding a smooth relative movement of components during the thermal cycle, that could cause an excessive flow down of the brazing material, figure 9.

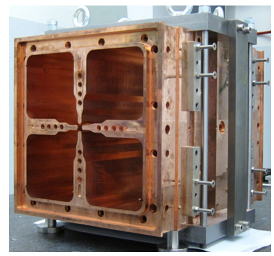


Figure 7: Module 16 dry assembled before the machining of the common planes

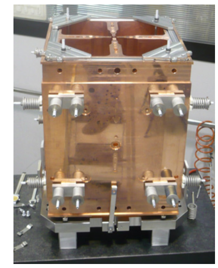


Figure 8: Module 16 assembled with the brazing tooling

The Brazing Procedure, 1st Step

We used Palcusil 10[†] as brazing material (optimal wetting of the surfaces while allowing for more brazing cycles repairs).

The optical inspection of the brazing joints showed an uniform distribution of the brazing material both on copper-copper and copper-st.steel.

The vacuum tightness of the cavity and of the cooling ducts was well below the specifications (1x10-9 mbar/sec*l).

Nonetheless a relative displacement between the "Ts" and the "Es" profiles was found.

This effect is explained by the relevant different expansion between CuC2 and AISI316LN.

The st. steel ring was not brazed in the first step of the first prototype module. Besides this the structural schemes are slightly different since on the first case the components are separated while in the other they are strictly joined.

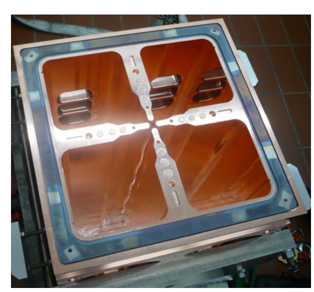


Figure 9: Module 16 after the 1st brazing step.

The Brazing Procedure, 2nd Step

The brazing material used is Cusil[‡]. During this step all the remaining st. steel components are brazed, figure 10. We encountered 2 problems.

[†] Palcusil 10 Composition: 59% Ag, 31 % Cu, 10% Pd; liquidus: 854 °C, solidus: 824 °C.

[‡] Cusil Composition: 72% Ag, 28% Cu; liquidus : liquidus: 780 °C, solidus: 780 °C.

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The junctions between the end side flanges and the copper were just partially brazed (as verified by US inspection).

The dimensional check of the cavity showed unexpected deformations.

The reasons:

- we discovered that the heat treatment of the end side flanges was not done following our specifications (the cooling step was too fast thus resulting on an ineffective annealing process);
- again the relevant different expansion between CuC2 and AISI316LN.

Since the brazed connection was too poor, a 3rd brazing step (using Incusil 10*) was performed to join the copper and the st. steel end side flanges by means of a series of pins, figure 11.

Beside all these problems the module 16 fulfills the specifications in terms of geometrical tolerances and vacuum tightness.

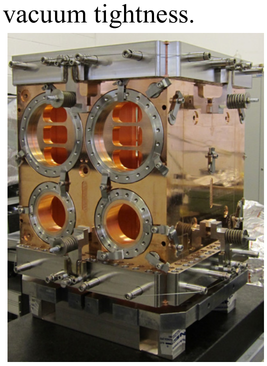

Figure 10: Module 16 before the 2nd brazing step

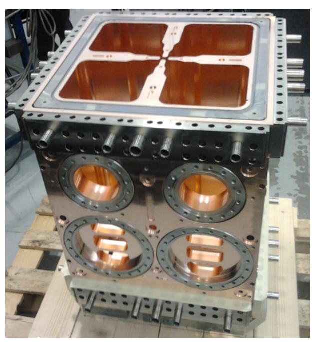

Figure 11: Module 16 after the 3rd repair brazing

Improvements - the results

Keeping in mind the problems found on module 16, a wide range of data for the thermal behaviour of copper and AISI316 were registered in the technical literature [2, 3].

We decided to perform some test with the peculiar material and dimensions to determine the overall relative expansion during our typical brazing cycles.

The tests results were better approximated by the material data as reported in reference [3]. Consequently our design was modified as follows:

- the sealing st. steel ring: any contact between copper and ring on the “Ts” sides (gap about 0.3 - 0.5 mm) was embedded, while the nominal coupling brazing tolerance on the “Es” sides was maintained to ensure a relevant coupling pressure all along the thermal cycle (accepting the residual local deformation at the joint level), figure 12;
- the end side flanges: some almost passing through incisions were introduced, softening the end side flanges stiffness, while ensuring a continuous brazing surface. The local expansion of the cavity was limited to a value around 0.01 mm, figure 13.

All these modifications were introduced and verified on the 1st brazing step of module 17 (sealing st. steel rings) and on the 2nd brazing step of the second prototype module (the incision solution was tested just at one side in order to see the differences).

We developed a more compact and effective constraint fixation made by TZM springs.

This allows for an easier positioning while increasing the contact pressure at high temperature. A more distributed number of constraints are now available.

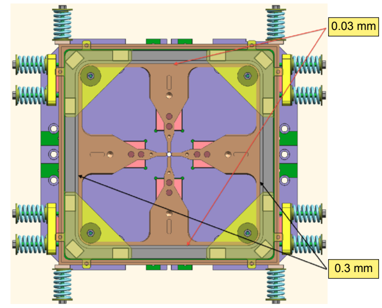

Figure 12: New design of the coupling between copper and sealing st. steel ring avoiding contact with the “Ts”

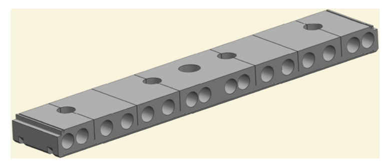

Figure 13: New design of the end side flanges with the incision to reduce the stiffness

WHAT NEXT

The single brazing method will be applied for the first time on the module 15 (October ’12).

We assigned a new contract for the production of SuperModule I and the production will start soon.

The production of SuperModule II will be done within INFN. The machining of components is already started.

AKNOWLEDGEMENT

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[3] N. C. Anderson, Lectures in Ceramic Metal Joining, Amsterdam, 1996.

* Incusil 10 Composition: 63% Ag, 27% Cu, 10% Sn; liquidus : liquidus: 730 °C, solidus: 685 °C