PREPARATION AND INSTALLATION OF IFMIF-EVEDA RFQ AT ROKKASHO SITE

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Abstract

The IFMIF-EVEDA RFQ is composed of 18 modules for a total length of 9.8 m and is designed to accelerate the 125 mA D+ beam up to 5 MeV at the frequency of 175 MHz [1]. The RFQ is subdivided into three Super-Modules of six modules each. The Super-Modules were pre-assembled, aligned and vacuum tested at INFN-LNL and then shipped to Rokkasho (Japan). At Rokkasho site a series of test were performed in order to verify the effect of the shipment on the cavity. The assembly debug, shipment equipment and the sequence of operations are described in this paper.

INTRODUCTION

IFMIF-EVEDA RFQ is divided into three SuperModules (SMs), each one composed of six modules. Two over three SMs were produced by two external companies and one was produced in house at INFN [2]. This subdivision was set to reduce production risks and revealed to be very effective. SM1 was produced by RI Research Instruments GmbH, SM3 was produced by CINEL Scientific Instruments S.r.l. and SM2, as just mentioned, was produced in house. SM3 and SM2 modules were produced compliant to the RF constrains while SM1 production was stopped due to frequency unconformities emerged after brazing of four over six modules. Measured nominal frequencies were, on average, 850 kHz higher than design frequencies. One possibility was to recover out of frequency using tuners range but, in this way, tuners range devoted to field errors compensation would reduce too much. For these reasons a mechanical recovery solution was studied for the four modules. The implementation was done by INFN and Cinel Company. Solution consisted in the machining of eight rectangular apertures on the external surface of each module to reduce its frequency (Figure 1). Vacuum closure was guaranteed by copper plugs sealed with Indium wires. Indium sealing was tested at high temperature in order to validate that this solution is compatible with baking process. Tests showed that no problem is encountered up to 100 °C that will be the maximum temperature reachable during RFQ bake-out.

Recovery actions were successfully concluded in September 2015. Moreover, the remaining two modules, whose production was stopped before brazing, were successfully brazed at INFN Legnaro in the same period.

SUPERMODULES ASSEMBLY AT LNL

SMs assembly started with SM2. Alignment of the modules was done under laser tracker supervision. A total of seven 8 mm in diameter cylindrical holes were machined on each module for alignment purpose. Each module can be adjusted in transversal position respect to the beam axis, using three main screws for vertical positioning and four small screws for horizontal one. After modules axes reach collinearity, modules can be moved close together sliding on two couples of rails linked to each module and previously aligned with module axis. Approaching process is followed by laser tracker. At the beginning a Garlock metallic C-seal helicoflex was used for modules coupling. The sealing helicoflex had to be squeezed by two stainless steel frames brazed on the modules copper surfaces. This had to guarantee vacuum tightness and RF joint.

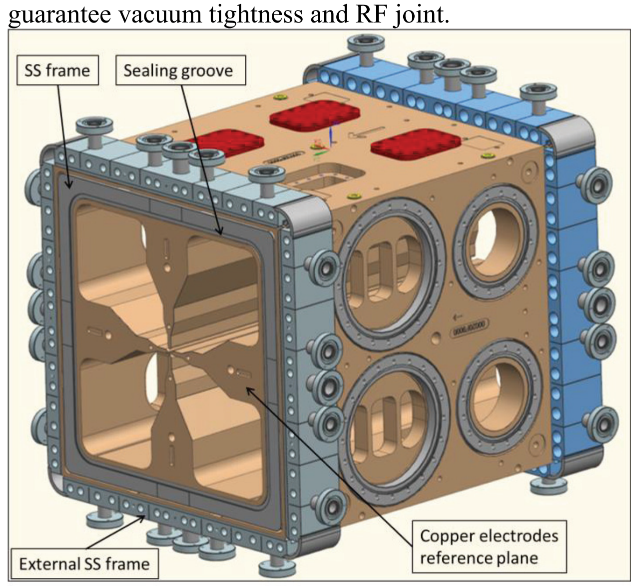

Figure 1: Module M2 layout. Rectangular apertures for frequency recovery are visible.

The first coupling operations revealed some weak points in the procedure. First of all, Garlock C-seal model required too much pressure (higher than that written into specifications) to be squeezed at nominal dimension and this pressure was enough to deform the brazed copper surfaces under stainless steel frame. Moreover in some cases, modules axes and modules main flanges had perpendicularity tolerances exceeding optimum range. As a consequence helicoflex compression was not uniform and this

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caused uncontrollable movements of the modules during assembly. In these conditions, final misalignment of the modules could result as bad as 0.15 mm in transversal position and as bad as 0.3 mm in longitudinal coupling.

To analyse better the problems, all the modules were measured with FARO Ion Laser Tracker using interferometric option. In particular sealing grooves depths, stainless steel frames planarity, external stainless steel flanges planarity and copper electrodes reference planes were measured (Figure1). Measurements confirmed that, in some cases, stainless steel frames were out of tolerance respect to axis perpendicularity. In some cases also helicoflex groove depth was out of tolerance.

To solve the various problems, some changes were implemented:

- Garlock helicoflexes were substituted with American Seal energized springs helicoflexes requiring half of the pressure to be compressed at nominal thickness.
- Eight stainless steel calibrated spacers were machined to be located between external SS modules frames. Spacers can be machined with different thickness according to laser tracker module characterization measurements.
- Groove depth in modules M9, M10 and M11 was increased and two special energized spring helicoflexes were used for the sealing.

With these improvements, it was possible to reach a reduction of module transverse misalignment down to 0.03 mm and longitudinal one down to 0.04 mm. In the meantime the helicoflexes compression depths recovered the nominal range for all connections.

SUPERMODULES SHIPMENT

The three SMs were completely assembled at LNL on January 2016. Before packaging, all the SMs were successfully tested in vacuum and filled with nitrogen gas.

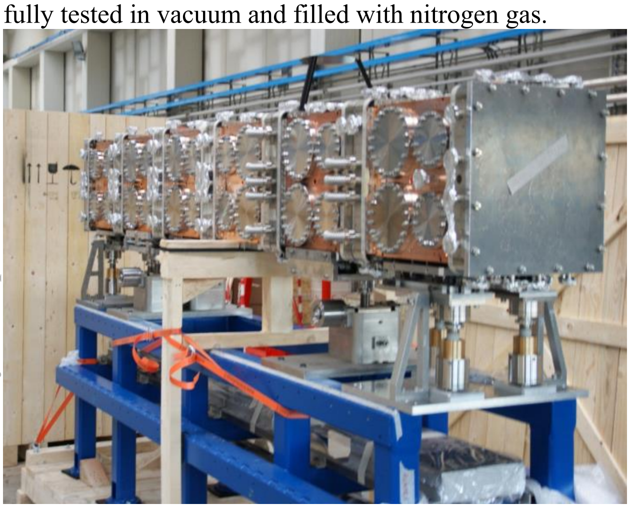

Figure 2: Assembly of the SM in the wooden box before shipment.

Rubber spacers were used between SMs support feet and the wooden platform constituting the package base. A central wooden support with rubber interface and two provisional supports were added to the SMs to reduce the weight on each support (Figure 2).

	Event	Axis	Date/Time	Modulus (g)	Temp (°C)
First Alarm	0	Z	17/02/2016 05:24:09	2,23	14,20
First Warning	1	Z	17/02/2016 22:52:28	1,27	13,50
Most Severe	5	Z	07/04/2016 00:38:52	2,93	17,20
Event Summary	11 Events (6 Warnings, 5 Alarms)				

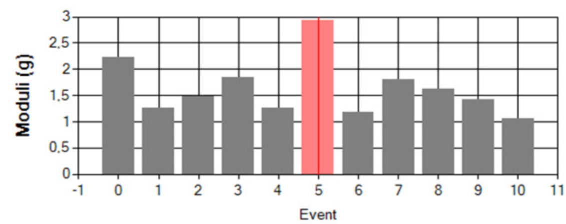

Figure 3: Data extrapolated from the shock recorder mounted on SM2.

Shock recorders, Shocklog 298, were screwed on the top of the SMs, one for each of them. They were programmed in such a way to start a continuous 8 s recording when acceleration overcome 1 g. In normal condition, that is when acceleration was below threshold, shock recorders made one acquisition (time slot) every 20 s. An example of shipment log is showed in Figure 3 relative to SM2. Supermodule was transferred to Milan airport by truck, to Frankfurt airport by plane, to Tokyo airport by plane and to Rokkasho site by truck. At the end, apart from traveling, it experienced four loading and four unloading operation. During the journey, the first three events were registered in Milan, Frankfurt and Tokyo respectively, all the others events were generated in Rokkasho during unpacking of the wooden boxes. Event logger for the others SMs were quite similar confirming that unpacking operation in Rokkasho was the first cause of shocks for the cavity. After SMs unpacking vacuum tests confirmed a vacuum leak lower than $2x10^{-10}$ mbar-l/s.

RFQ ASSEMBLY IN ROKKASHO

RFQ was not assembled in its final location because injector commissioning was not concluded. However, to test alignment and coupling procedure, it was assembled on the nominal beam axis but shifted by one supermodule towards high energy side [3]. Considering that central feet of the SM1 support stand have the same inter-distance respect to SM2 and SM3, it was possible to use SM2 and SM3 anchoring system to place SM1 and SM2. For SM3 new holes were drilled on the floor on the MEBT location trying to maintain a 10 cm minimum distance between MEBT anchoring holes and SM3 provisional ones. For this reason it was possible anchoring SM3 on just four over six connection points.

SMs and their associated support stands were prealigned using a rough alignment system able to regulate position with 0.5 mm precision over ±20 mm range in all directions. SMs were then precisely aligned within 0.05 mm respect to nominal references using precise alignment system (Figure 4).

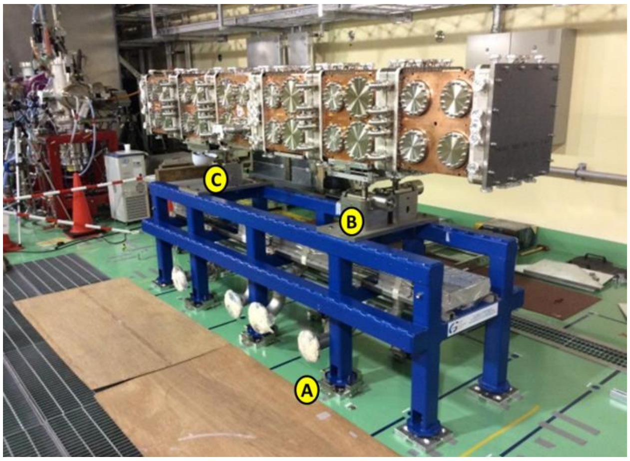

Figure 4: SM1 in its provisional installation place. Rough alignment systems (A) and precise alignment systems (B and C) are visible.

It is important to notice that during coupling of the SMs, alignment of the interface modules axes has higher priority respect to alignment of the SMs respect to reference beam axis. This means that low energy plate and high energy plate of the RFQ are forced to be on beam axis while single modules axes can be as far as 0.2 mm from the nominal beam axis in the vertical component. In particular, maintain 0.03 mm maximum misalignment between modules, RFQ axis move down respect to nominal beam axis up to -0.2 mm at the level of coupling between SM1 and SM2. Inside SM2, RFQ axis recover nominal beam axis and overcome it at the interface between SM2 and SM3 (+0.05 mm). Inside SM3, RFQ axis move from +0.05 mm up to -0.02 mm.

Just after RFQ assembly, dummy tuners and bead pull system were installed on the RFQ cavity to find the optimum configuration for cavity tuning. Bead-pull campaign to optimize end plates and tuners penetrations started at the end of April 2016 and took two weeks.

FINAL TUNERS

In parallel to the RFQ installation at Rokkasho, final tuners were machined and brazed at LNL. Copper needed for tuner machining was reclaimed by RFQ modules machining scraps. After machining, semi-finished tuners were brazed at LNL (Figure 5).

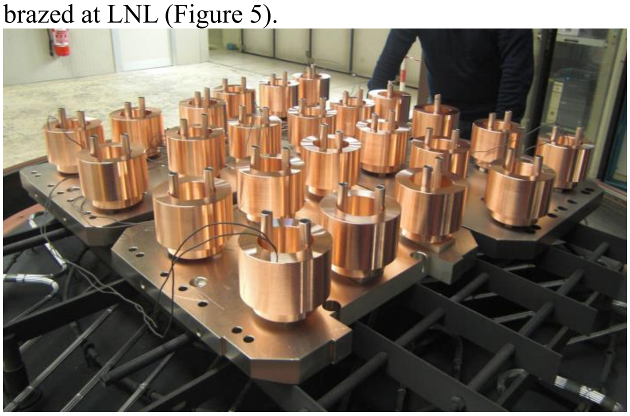

Figure 5: Semi-finished copper tuners ready for brazing at LNL furnace.

Final tuners were machined at required quotes according to RFQ bead pull measurements results [4]. Machining was done in three steps in order to maintain enough tuning margin up to the conclusion of the process. In the first step copper termination plates and 16 copper tuners were replaced to dummy termination plates and dummy tuners in Rokkasho. Bead pull measurements showed that final low energy termination plate caused a small change in the field flatness that was recovered by changing the penetration of the four tuners located near the plate. In the second step, 43 aluminium tuners were substituted with copper ones and no changes appeared on the field flatness. At the end, the remaining 49 aluminium tuners were replaced with the copper ones without affecting the field (Figure 6).

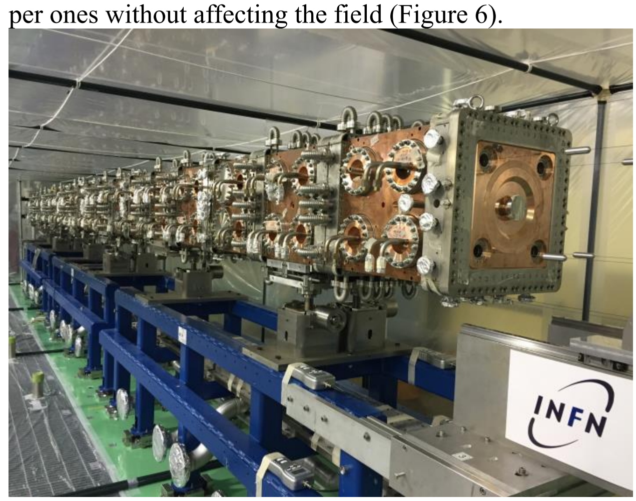

Figure 6: IFMIF EVEDA RFQ assembled and tuned at nominal field value.

CONCLUSION

Final measurements confirmed an extremely good cavity quality factor [4]. On November 2016, after termination of injector commissioning, it will be possible to move the cavity in its final location. High power couplers will be installed and system bake-out will start. Cavity conditioning is foreseen on March 2017.

ACKNOWLEDGEMENT

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