352.2 MHz HOM DAMPED NORMAL CONDUCTING ESRF CAVITY: DESIGN AND FABRICATION*

V. Serrière, J. Jacob, B. Ogier, L. Goirand, A. Triantafyllou,
A.K. Bandyopadhyay, D. Boilot, ESRF, Grenoble, France

Abstract

The ongoing ESRF upgrade included an option for an increase of the storage ring current from 200 to 300 mA, which has been tested successfully with the existing RF system. At this current level the HOM tuning of the existing five-cell copper cavities becomes extremely delicate and in view of a future reliable operation in user mode, new HOM free normal conducting cavities were developed at the ESRF. The design is based on the existing BESSY/ALBA cavity. However, several substantial modifications have been implemented and different fabrication processes elaborated to improve the design. Three operational prototypes are being delivered by three manufacturers and will be fully tested on the ring. Although the 300 mA option has finally not been retained for the first phase of the ESRF upgrade, the aim is now to validate the new cavity design for a possible later increase in current.

INTRODUCTION

The new ESRF cavities with ridge waveguide HOM dampers were designed for an unconditionally stable operation at 300 mA, 9 MV of total accelerating voltage with 18 cavities installed on the storage ring. Three design margins were set: a power capability for 500 mA, a threshold for longitudinal coupled bunch instabilities above 1 A and a possibility to operate the machine with only 12 cavities [1, 2]. The electromagnetic design and in particular the required low level of longitudinal HOM impedances were checked on aluminium prototypes early in 2009. In parallel, the assembly for a UHV compatible high power copper cavity was designed.

GENERAL DESIGN CONSIDERATIONS

In the BESSY/ALBA design, inevitable gaps remain between the ridges of the HOM dampers that protrude into the cavity and the sleeves of the cavity ports, which lead to unexpected thermal problems [3]. The suppression of these gaps constitutes the main improvement of the ESRF design shown in Figure 1. It is achieved by electron beam welding the coupling sections of the HOM dampers, to the cavity body. After re-machining, the faces of the coupling sections follow perfectly the inner diameter of the cavity body. The two large HOM dampers designed to damp the lowest HOM are prolonged by an intermediate section. This is not required for the smaller damper on top of the cavity, designed with a higher cutoff frequency to provide additional damping of the highest HOM.

The various sections of the HOM dampers are connected face-to-face. As the surface currents of the fundamental ridge waveguide mode are concentrated on the ridges, the ridge faces of the coupling sections and the upper HOM absorber are equipped with RF springs to ensure the electrical continuity. The length of the coupling sections is such that the fields from the accelerating cavity mode, under cutoff in the dampers, are sufficiently decayed and don't damage the RF contacts [1,2].

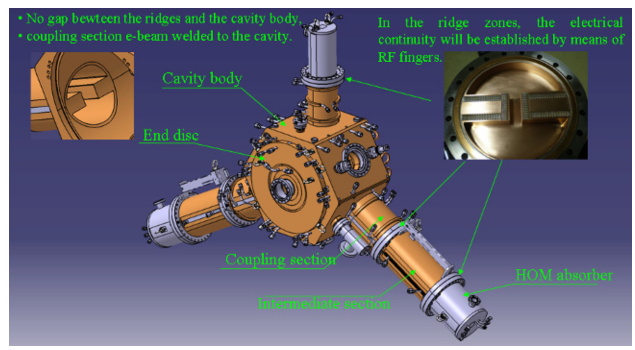

Figure 1: General design of the copper prototype.

In May 2009, a call for tender was sent to four pre-qualified companies for the optimization of the fabrication process and the delivery of a high power copper prototype. In June 2009, three technically conforming offers were received from RI Research Instruments, SDMS and Cinel. A first prototype following the initially specified mechanical design was ordered from RI. SDMS proposed an interesting alternative fabrication method, which the ESRF considered worth being developed further. The ESRF then worked out the detailed mechanical design with a full set of new fabrication drawings. A second cavity was ordered from SDMS in November 2009 according to this alternative design. In order to qualify a third company for the possible later series fabrication, a third prototype was ordered in December 2009 from Cinel, who evaluated both approaches and selected the alternative design.

MECHANICAL DESIGN

Initially Specified Design

Figure 2 summarizes the main steps in the cavity assembly. As shown on top left, the intermediate sections are e-beam welded on the cavity body with a penetration of at least 15 mm. As proposed by RI, an over-thickness on the inner diameter of the cavity was used as beam stop and machined before the final assembly. The cooling

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system of the cavity body is made of long drillings in the cavity walls (parallel and perpendicular to the longitudinal axis) and in the ridges of the bigger coupling sections. Then, as shown on the top right, all the flanges, outlets, cooling pipes and plugs are vacuum brazed on the cavity body in a single operation. In parallel the end discs are assembled by brazing, also in one step: the outlet of the beam pipe, plugs and pipes of cooling system. The cooling system of the end-disc is made of long drillings in the discs and the noise cones, as shown on cutting views A-A and B-B in Figure 2. Note that the frequency tuning is done by turning an over-thickness of one end-disc, as shown in detail D. After the RF tuning, the end-discs are brazed on the cavity body.

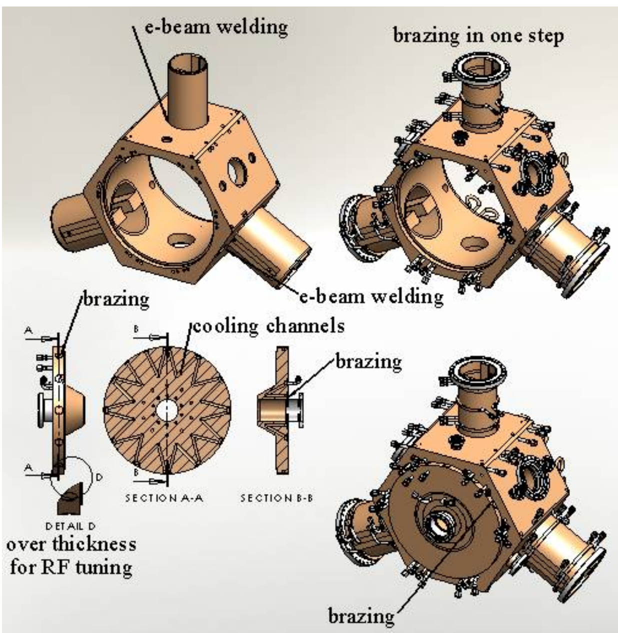

Figure 2: Main assembly steps of initial specified design.

The ridges of the coupling and intermediate sections are water cooled. Grooves are machined on those end faces that are equipped with RF contact stripes.

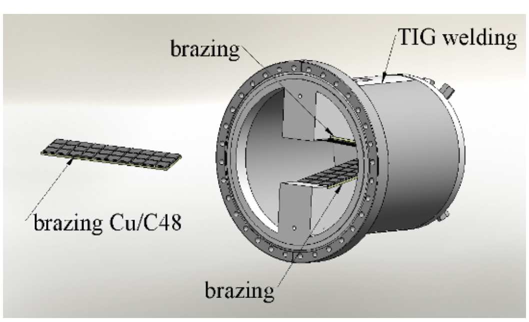

Figure 3: HOM absorber assembly.

The HOM absorbers are assembled as shown in Figure 3. The ferrite tiles are brazed on copper plates, which are then brazed on the ridges of the 316LN HOM damper bodies. They are then closed with TIG welded stainless steel covers. The HOM absorbers are also water cooled by means of long drillings in the ridges.

Alternative Design

In their reply to the call for tender, SDMS proposed to build the cavity body from three smaller sectors rather than a single copper block, and then to assemble these sectors by e-beam welding. They replaced the brazing of the outlets and end discs by e-beam welding. For the cooling system, they proposed to replace the long drillings with water cooling box, by milling the cooling channels into the copper parts and then closing the channels with e-beam welded lids, as shown on top of Figure 4. The definition of the cooling channels and lid shapes has been optimized by the ESRF team to obtain an efficient cooling and to withstand the mechanical stress induced in the welding area by water at up to 15 bar. The coupling sections and the outlets are then connected to the sectors by e-beam welding from the inner side of the cavity. The end-discs have two cooling channels: drillings in the nose cone as in the initial design and a milled channel on the circumference. The “margaret” like shape minimizes the mechanical stress on the welding area.

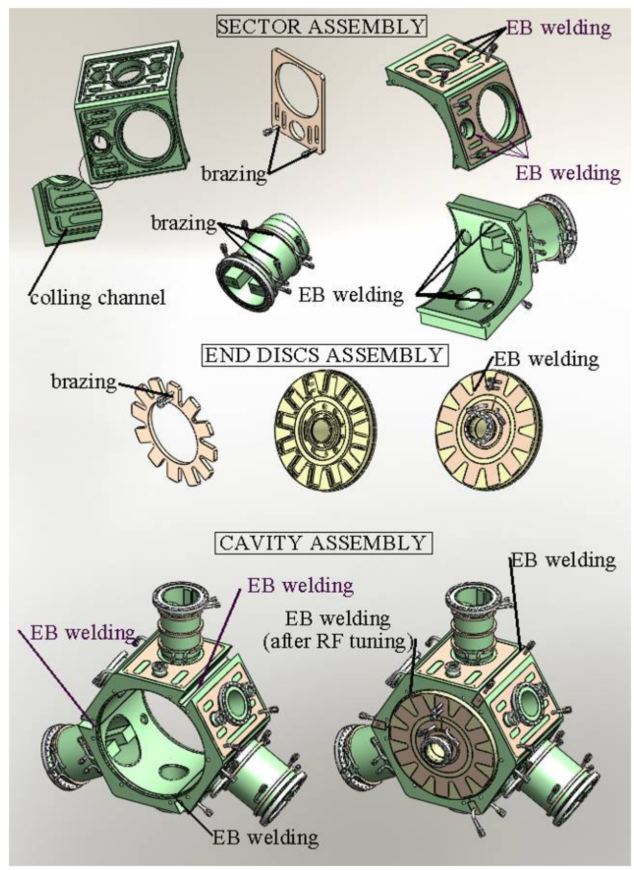

Figure 4: Main assembly steps of alternative design.

As shown on bottom of Figure 4, the three sectors are assembled by e-beam welding. The frequency is also tuned by turning an over-thickness on one end-disc before the e-beam welding assembly of the body and the discs.

The fabrication of the coupling sections and HOM absorbers is similar to the initial design.

FABRICATION

Both RI and SDMS have successfully fabricated and recently delivered the first two cavities. The fabrication progressed well, however, both manufacturers faced problems when connecting the huge ridge loaded cylindrical coupling sections to the cylindrical cavity bodies by means of electron beam welding. This welding process appeared more challenging than expected.

On the RI cavity the electron beam weld essentially exhibited some porosity on each connection of coupling section to cavity body, which could have been detrimental to the vacuum behaviour under high RF power. The problem could finally be solved with a superficial smoothing laser beam weld.

In the case of the SDMS cavity, one of the e-beam welds was not vacuum tight. After several attempts with repair welds the coupling section even fell off the cavity body. The subsequent repair required the fabrication of an intermediate copper ring, which finally allowed welding the whole together by means of careful electron beam welding.

The Cinel cavity is expected by the end of 2011. The end discs and intermediate sections have already been assembled. The subcontracted e-beam welding of the coupling sections and the outlets on the three body sectors is under way. The process for the brazing of the ferrite tiles to the HOM dampers is also still under investigation.

COMMISSIONING AND OUTLOOK

The first cavity was delivered at the ESRF by RI on 15th June 2011. Low power RF measurements confirmed a quality factor of 33800, at the upper end of the expected 30000 to 35000 range, resulting in a shunt impedance of 4.9 MΩ for the accelerating mode. The measurement of longitudinal impedance spectrum in Figure 5 confirmed a very efficient HOM damping, even a factor 2 better than the design goal.

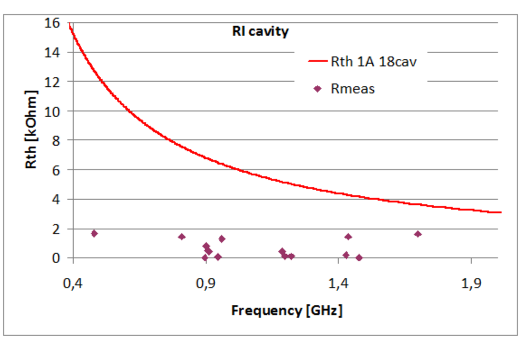

Figure 5: RI cavity - longitudinal HOM measurements.

The RI cavity passed the vacuum acceptance test with a final pressure better than 7e-10 mbar, after a few days of baking at 130 °C. As shown in Figure 6, the RI cavity was installed on the RF power test stand in August 2011 for power conditioning. After a few days, 500 kV were obtained in CW with a very good vacuum pressure. The RF conditioning will be pursued in the coming weeks up to an accelerating voltage of 750 kV in CW. In October 2011, the RI cavity will be installed on the storage ring cell 25 for full beam tests, in place of the five-cell cavity #5 that was removed in January [4,5].

The SDMS cavity was delivered on 20th July 2011 and is under preparation for the vacuum acceptance test in the RF lab as shown in Figure 7. The RF conditioning is foreseen in the coming months and the cavity will be installed on the storage ring in summer 2012 in place of the RI cavity. The beam tests for the CINEL cavity are foreseen in 2013.

Once tested individually on cell 25, the three HOM damped cavities will be installed together in-between the two canted undulators of cell 23, which will be the first ESRF straight section to be lengthened from 5 to 7 m [4,5]. They will be powered by three 150 kW solid state amplifiers, thereby constituting a prototype RF unit, that will replace klystron powered five-cell cavities if an increase of the ESRF current from 200 to 300 mA is foreseen in a later ESRF upgrade phase [5].

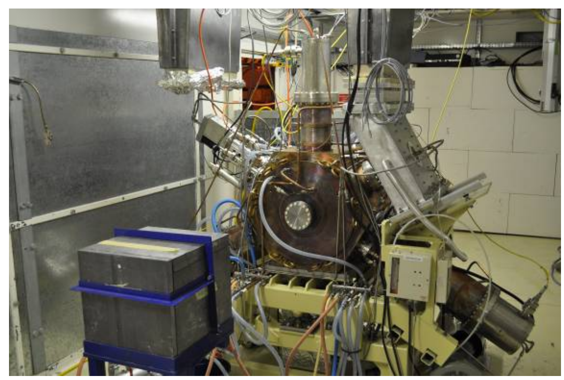

Figure 6: RI cavity in the RF power teststand.

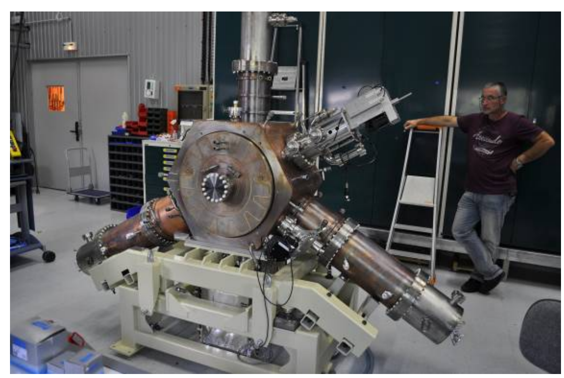

Figure 7: SDMS cavity in the RF lab.

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