# EXPERIENCE ON DESIGN, FABRICATION AND TESTING OF A LARGE GRAIN ESS MEDIUM BETA PROTOTYPE CAVITY

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*Abstract*

We report on the design, fabrication and testing of an ESS Medium Beta prototype cavity made with Large Grain Niobium sheets sliced from an ingot provided by CBMM. The peculiar choices during the fabrication process related to the Large Grain Niobium material are described. We present also the results of the cavity test at cryogenic temperature and the dedicated quench diagnostic.

## INTRODUCTION

INFN-LASA is in charge of the procurement of the 36 Medium Beta Cavities (β = 0.67) for the ESS proton Linac. As part of this activity, we have designed a prototype cavity "plug compatible" [1] with the boundaries required by ESS interface specifications and necessary for the installation in the Cryomodule at CEA [2]. Two prototypes of these cavities have been built and treated at the Ettore Zanon S.p.A., following a "build-to-print" scheme, the same successful strategy developed for the 800 European XFEL 1.3 GHz cavities [3]. To validate the cavity design and the production process, one cavity was built with Fine Grain Niobium, as foreseen for the series. A second prototype was instead produced using Large Grain Niobium to explore the possibilities and potentialities of this material.

In this article, we present our experience on the material preparation, fabrication and testing of the LG Niobium cavity based on our design for ESS Medium Beta cavities.

## MATERIAL PREPARATION

The main motivation to build cavities based on Large Grain Niobium is to explore both the physical potential benefit due to higher achievable thermal stability coming from the "phonon peak" in the thermal conductivity and the cost benefit due to lower bare material prices and, possibly, simplified fabrication process [4].

CBMM (Brazil) produced a high RRR (≈ 300) Large Grain Nb ingot with a diameter compatible with the Medium Beta and High Beta ESS Superconducting cavities (about 480 mm), by using a special crucible and metallurgic techniques. CBMM produced, from this ingot, two shorter and lighter ingots (about 200 kg). Figure 1 shows the two ingots at Heraeus premise, in preparation for the slicing process, just after their arrival from CBMM.

Heraeus GmbH in Hanau sliced then the ingot into disks with the proper thickness necessary for the cavity fabrication [5] using a multi-wire sawing machine adapted to our large ingot diameter. Figure 2 shows the Large Grain sheets ready after slicing.

Figure 1: CBMM Large Grain ingots at Heraeus in preparation for the slicing process.

After the slicing process, the Nb sheets were chemically etched (BCP 1:1:2) to remove few micrometers of mechanically damaged surface layer.

Afterwards, to reduce the hydrogen content increased during the sawing operations, the sheets were heat treated at 700 °C in a vacuum furnace, dedicated to treatment of Superconducting cavities and their components.

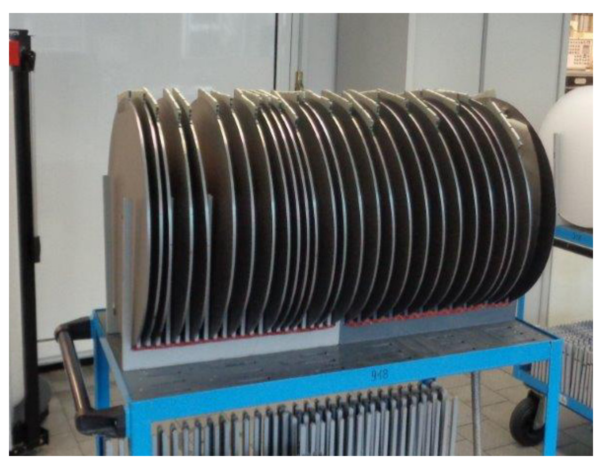

Figure 2: Large Grain ingots after slicing at Heraus.

## CAVITY FABRICATION

### *Subcomponents*

The cavity fabrication follows a standard procedure where the half-cells are deep drawn from the sheets and, then couple of half-cells are welded at the iris to form

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dumb-bells. Figure 3 shows a Large Grain dumb-bell ready to be welded to form the cavity.

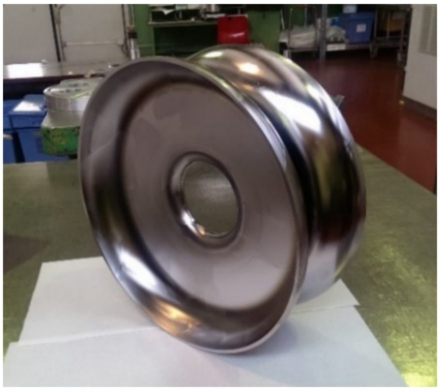

Figure 3: Large Grain dumb-bell ready to be welded to form the cavity.

End-Groups are also prepared and then these components and the dumb-bells are welded together to form the cavity. The final goal is to reach the proper frequency and length of the cavity within the tolerances specified by ESS. For doing this, the dumb-bells and the end-groups length needs to be trimmed to compensate for geometrical imperfection during the fabrication process. Moreover, using Large Grain material, also the enhanced grain boundaries contribute to modify the inner volume of the half-cell in an uncontrolled manner. Figure 4 shows the frequency spread versus dumb-bell length for the three inner dumb bells.

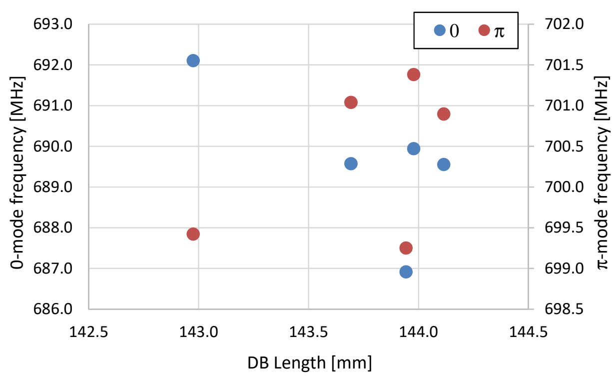


Figure 4: Distribution of 0-mode (blue dots) and π-mode (red dots) frequency versus dumb bell length.

The spread in dumb bell frequencies is not clearly related to the dumb bell length, as one would expect. This, as noted before, is due to the presence of the large grain boundaries, but also to the deformation of the dumb bell during the trimming operation due to their large size. We have observed a similar behaviour also during the production of the Fine Grain components.

### *Treatments*

The Large Grain cavity, after final electron beam weld, was then chemically treated to remove about 180 µm from the inner surface. During this process, we monitored the temperature of the outer surface of the cell and observed an increase of the cell on the exit side of the acid up to 38 °C, while the acid temperature did not exceed 17.2 °C. Followed a heat treatment at 600 °C for ten hours, to remove hydrogen produced during the previous chemical etching. Figure 5 shows pressure in the oven during the heat process.

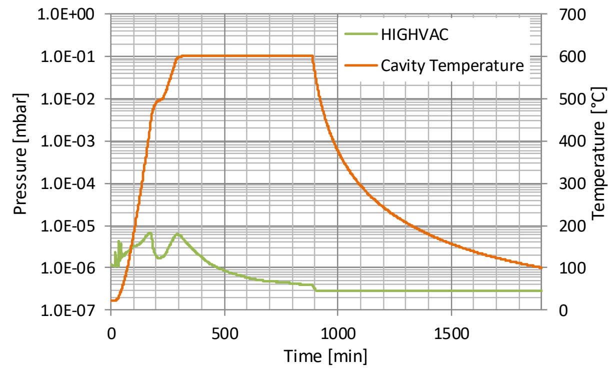


Figure 5: Pressure and temperature trend during the cavity heat treatment for dehydrogenation after main chemical processing.

The heat treatment was limited to 600 °C, because some components of the cavity are made of Titanium and, we want to prevent any pollution of the cavity surface and damage to Titanium parts due by higher temperatures. The major contribution to the pressure composition is hydrogen that is reduced by at least 20 times during the heat cycle. Measurement on Nb samples present in the oven together with the cavity show a full recovery of the RRR as before the chemical process.

### *Tuning*

After the heat treatment and before the final BCP attack, the cavity was tuned to the required frequency by a bead pull system. The final field flatness is greater than 98 % at the required frequency at warm at this stage of the preparation of 703.1 MHz.

Despite the before mentioned irregularities during dumb bell preparation, also the cavity length was well within the required tolerances.

### *Final Preparation*

The cavity was then prepared for the cold test. 20 µm of the inner surface was removed by BCP, and then the Pick Up and Main coupler antennas were installed on the cavity together with the blank off flanges. The prepared cavity was then shipped to LASA ready for cold test.

## CAVITY TEST

The Large Grain cavity was tested at LASA, in the upgraded Vertical Test Infrastructure.

After the Fine Grain cavity test [6], we went through a review of the facility to reduce the magnetic field contribution to the residual resistance of the cavity. As an outcome of this activity, the maximum magnetic field we achieved was of 8 mG. Further reducing this value requires major modifications to the insert that are planned in the near future.

### *First Test*

The Large Grain cavity was first tested in December 2016. Figure 6 shows the power rise results together with the radiation dose measured on top of the cryostat, on the vertical of the cavity position.

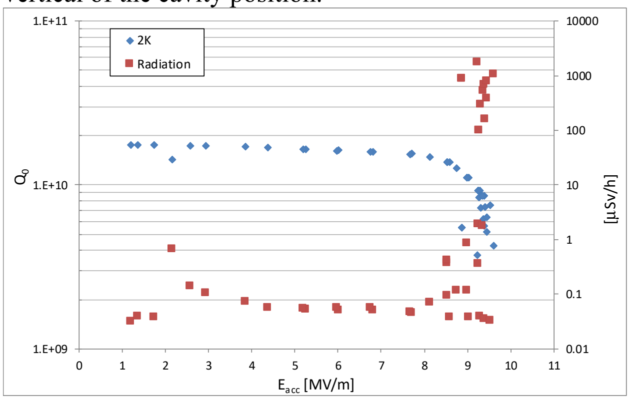


Figure 6: First test of the Large Grain cavity where large radiation dose was observed.

The quality factor of the Large Grain cavity at low field was comparable with the Fine Grain cavity. The cavity quenched just below 10 MV/m with a large radiation dose. We observed already a soft multipacting around 2 MV/m (as expected by simulation [7]) clearly visible in a small drop of the $Q_0$ and in an increase in the emitted radiation. A second large increase of the radiation level was then measured around 9 MV/m. Again, this is a region of soft multipacting, easily process, as in the case of the Fine Grain cavity. In this case, instead, the radiation emitted was very high (up to 2 mSv/h) and the cavity quenched. Additional power rises at the all passband mode allow reducing the emitted radiation by four order of magnitude but still a higher value with respect to the Fine Grain cavity was present. During all these measurement, the quench field instead did not change. To cure the large radiation emission, we proceeded with an additional 20 µm BCP and a long "24-hour" High Pressure Water Rinsing.

### *Second Test*

The cavity was tested the second time in April 2017.

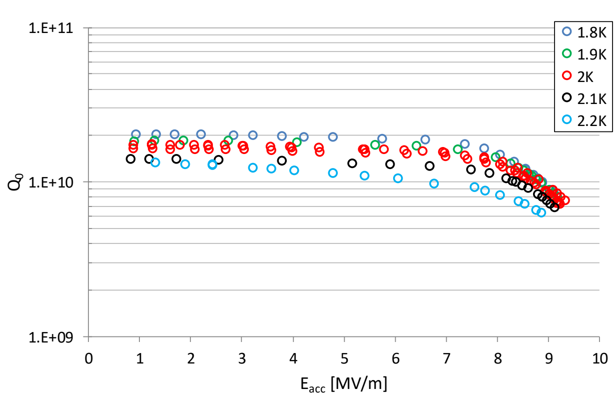


Figure 7: Large Grain cavity power rises at different temperature at the fundamental frequency.

Figure 7 reports on the results obtained in the fundamental mode at different temperature of the LHe bath.

As for the previous test, the Q0 at low field was in the low 1010 range. Moreover, being similar the Q0 slope at the different temperatures, it seems to indicate that the phonon peak was not "activated". Unlike the previous test, the radiation dose was in the background level and hence not measurable. Nevertheless, as for the first test the cavity quenched just above 9 MV/m at all the different temperatures. The difference in quench fields between the different LHe bath temperatures suggests a limitation of dissipated power at about 25 W, well below the cryogenic capacity of our plant set at about 40 W at 2 K. A mode analysis shows a nearly constant quench field on all the different modes, indicating a distributed limitation. We used second sound detectors to identify quench spots and we found possible sites on cell 1, 3 and, 5 (starting from the PU) [8].

## CONCLUSIONS

We produced and tested a Medium Beta Large Grain cavity prototype based on INFN-LASA designed developed for ESS.

The main difference with respect to the Fine Grain cavity prototype in the fabrication phase was in the RF characterization of components and the response to trimming operation. Instead, during all mechanical and welding operations the behaviour was similar to the Fine Grain one. The treatments were similar but we noticed a greater increase of the cavity top outer wall temperature during the chemical etching.

The low field quench during the power rise is still under analysis. We have not noticed a major change in $Q_0$ slope at different temperatures, indication that we did not enhanced the phonon peak possibly due to the low heat treatment temperature. The large radiation dose measured during the first test was clearly cured with a second 20 µm BCP and "24-hour" HPR.

The reasons of the premature quench at low field are still not clear. Based on our measurement evidence, the mechanism seems to be a few spots quenching at similar accelerating field. The power limit at about 25 W might be due either to low thermal conductance of the Nb sheets or to a bad heat transfer between the cavity and the LHe bath. These hypotheses are under investigation as well as analysis of the data acquire so far.

## REFERENCE


[1] P. Michelato *et al.*, "INFN Milano – LASA Activities for ESS", in *Proc. SRF2015*, Whistler, BC, Canada, 2015, THPB010.

[2] C. Darve *et al.*, "ESS Superconducting RF Collaboration", presented at *8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, MOPVA090, these proceedings.

[3] P. Michelato *et al.*, "ESS Medium and High Beta Cavity Prototypes", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, WEPMB011.





ISBN 978-3-95450-182-3

[4] P. Kneisel *et al.*, "Progress on Large Grain and Single Grain Niobium–Ingots and Sheet and Review of Progress on Large Grain and Single Grain Niobium Cavities", in *Proc. SRF2007*, Beijing, China, TH102.

[5] L. Monaco *et al.*, "Fabrication and Treatment of the ESS Medium Beta Prototype Cavities", presented at *8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, MOPVA090, these proceedings.

[6] A. Bosotti *et al.*, "Vertical Tests of ESS Medium Beta Prototype Cavities at LASA", *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, MOPVA063, these proceedings.

[7] J. Chen *et al.*, "Multipacting Studies in ESS Medium-Beta Cavity", presented at *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, MOPVA061, these proceedings.

[8] M. Bertucci *et al.*, "Quench and Field Emission Diagnostic for the ESS Medium Beta Prototypes Vertical Tests at LASA", presented at *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, MOPVA061, these proceedings.