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400 MHz SEAMLESS COPPER CAVITY IN THE FRAMEWORK OF FCC STUDY

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Abstract

In the framework of the FCC study the production of 400 MHz copper cavities is one of the key challenges for the development of more efficient superconducting RF cavities. Any progress on substrate manufacturing and preparation will have an immediate impact on the final RF performance, as it was demonstrated by the seamless cavities produced for the HIE-ISOLDE project. Spinning is a potential alternative to conventional production methods of copper single and multi-cells.

In this work is presented the first 400 MHz copper RF cavity prototype produced via Spinning at Laboratori Nazionali di Legnaro of INFN. The production process is explained starting from a copper sheet of 1150 mm diameter and 4mm thick to arrive to a seamless 400 MHz cavity.

Moreover, the metrology of the cavity and the analysis of the influence of intermediate thermal treatments among each steps of cold work are shown.

INTRODUCTION

Superconducting radiofrequency accelerating cavities are the heart of modern particle accelerators. One of the key challenges for FCC is the development of more efficient superconducting RF cavities. Any progress on substrate manufacturing and preparation will have an immediate impact on the final RF performance [1], as it was demonstrated by the seamless cavities produced for the HIE-ISOLDE project. The welded ISOLDE Quarter Wave Resonators show the typical Q-slope of thin films cavities (decrease of the Cavity Quality Factor at high accelerating fields) [2]. The issue was substantially reduced substituting the welding cavities with seamless ones.

In the RF Superconductivity field, the technology of seamless cavities is, among all other topics, perhaps the one that mostly requires a creative approach. More than elsewhere, this is the right place where researchers can give free rein to their imagination [3]. There are different techniques to produce a seamless cavity as for example spinning, hydroforming, explosive forming, electroforming etc. Spinning is a well-known forming technique to obtain seamless cavities and refers to a group of forming processes that allow a production of hollow, axially symmetric sheet metal components. The basic technique of spinning, which is common to this group of processes, consists of clamping a sheet metal blank against a mandrel on a spinning lathe, and gradually forming the blank onto the mandrel surface by a roller, either in a single step or series of steps [4] (Fig. 1). For its cheapness, today the spinning technique is largely used by the SRF community for the production of R&D cavities, both in niobium and copper. However, in the production of cavities for accelerators, the standard technique is still preferred. The traditional fabrication methods consist in the spinning, or deep drawing, of the two half-cells and a further electron beam welding on the equator. This protocol respects the dimensional tolerance in a large-scale production, which is a mandatory during the construction of a particle accelerator. Due to the non-symmetrical nature of the seamless spinning fabrication method, to guarantee the dimensional tolerance in a large-scale production thousands of cells required from FCC is one of the challenges of this research.

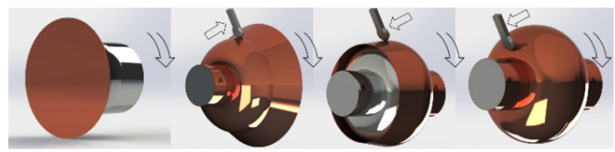

Figure 1: 400 MHz spinning process.

During the 2018 the INFN-LNL SRF group has been carrying out the R&D of the seamless 400 MHz cavities, producing two prototypes. The first 400 MHz copper cavity spun showed deep cracks near the cell iris, but it was fundamental to understand how to improve the process. For the 400 MHz cavity, at least three intermediate annealing in ultra-high vacuum furnace, at three different stages of spinning process, are necessary for the complete closure.

In November 2018, the first seamless 400 MHz copper cavity in the world was produced and in this paper is described the workflow starting from a copper sheet to arrive at the complete cavity.

EXPERIMENTAL PROCEDURE

In order to verify any kind of failure in the spinning process and adopt the right countermeasure, it was decided to proceed in parallel with the spinning of two cavities. The first part of the production of the cavity was the spinning of the first half cell (Fig. 2). The raw material was a sheet of OFE copper 1150 mm diameter and 4 mm thick provided by CERN from MKM GmbH. A first step of production corresponded with the deep drawing of the copper sheet to form and fix the copper on the tale. Immediately after the deep drawing the first half cell was spun.

After the production of the first half cell obtained with deep drawing and spinning as indicated in Fig. 2 and without any annealing, it was necessary to set up a thermal treatment to relax the internal stresses due to the cold work. The thermal annealing was provided in the LNL UHV furnace following the thermal cycle reported in Fig. 3. Starting from a degassing of the material at 200 °C for 24h,

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passing through a temperature pre-treatment at 300 °C for 2h and then the real thermal annealing at 500 °C for 2h.

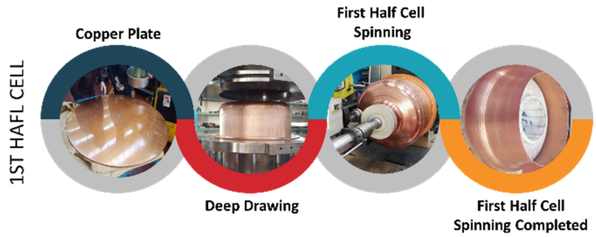

Figure 2: The first half 400 MHz cell spun.

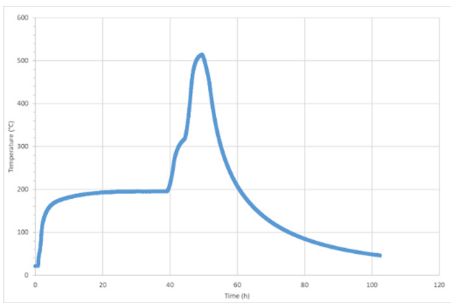

Figure 3: Thermal annealing cycle.

To produce the complete prototype of the 400 MHz cavity more than two annealing were necessary, due to the large amount of cold work required in the spinning process of such a big resonator.

In Fig. 4 the comparison between the two prototypes production steps is reported.

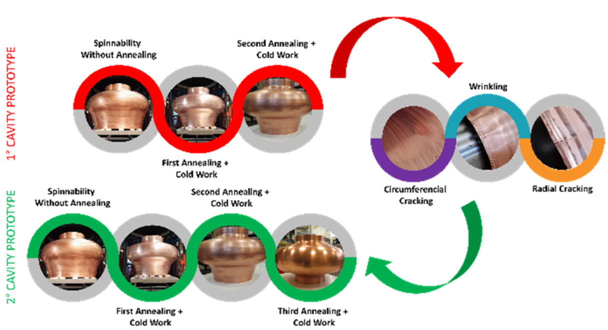

Figure 4: Comparison between the first and the second cavity production steps.

The first prototype production was used as a test, in order to understand the minimum number of intermediate annealing necessary to realize the 400 MHz resonator by spinning process. The material, after the annealing, was machinable, but during the spinning process the copper became harder and it was necessary to stop the process in order to avoid the complete cracking of the cavity.

The second prototype was produced using the know-how acquired during the first prototype production. In fact, a third intermediate annealing was introduced in order to reduce the amount of stress introduced in the second half cell production. Adding a third annealing step, the copper was more machinable than the first prototype and it was possible to close the cavity completely.

RESULTS

A visual inspection of the surface status and defects was performed at LNL. The first prototype closed with 2 intermediate annealing had some failure during the final steps of spinning process, as evidenced in Fig.5 immediately before the iris.

Figure 5: Visual inspection of the defects of the first 400 MHz cavity spun.

The second prototype of Cavity had two small cracks in the cut-off region again close to the iris (1cm from it) Fig. 6.

In Fig. 7 is reported the internal surface of the second cavity. It was very good, except for the cut-off, where the surface had an orange peel appearance. This is a typical feature of the spinning process when the material is not completely pressed against the mandrel.

Figure 6: visual inspection of the defects of the second 400 MHz cavity spun.

Figure 7: Visual inspection of the surface status of the second 400MHz (on the left the second half cell with an orange peel surface, on the right the first half cell).

The two cavities were sent to CERN to verify their dimensions, only the second cavity was measured. The circularities of cavity were evaluated in 4 different points: two in the first cut off (first half cell), one on the equator and one on the second cut off (second half cell). The measurement showed that the circularities did not respect the standard required (Fig. 8). One hypothesis was that the thermal annealing among each steps of spinning modified the circularities, relaxing the internal anisotropic stresses of the material. To confirm this hypothesis there was the circularity of the second cut-off, that respected the tolerance re-

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quired. In fact, the second cut off is the last part of the cavity spun and it does not undergo one additional thermal annealing. We are planning to design and install a specific cavity holder, during the annealings, clamping the cavity in its resting position, in order to prevent this behaviour. Moreover, the cavity once completed should be uniformly pressed against the mandrel moving the roll from the first to the second cut-off, this part was avoided for these two cavities in order to prevent a fatal cracking of the thin walls.

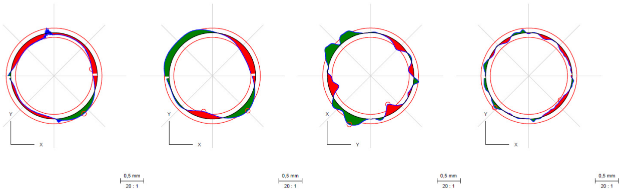

Figure 8: Circularities of the second 400 MHz.

The thickness profile of the second cavity, as expected from the asymmetric forming of the spinning starting from a Sheet of metal, changed along the cavity axis. This effect was well clarified observing the Fig. 9, where it was evidenced that the second half cell was under dimensions.

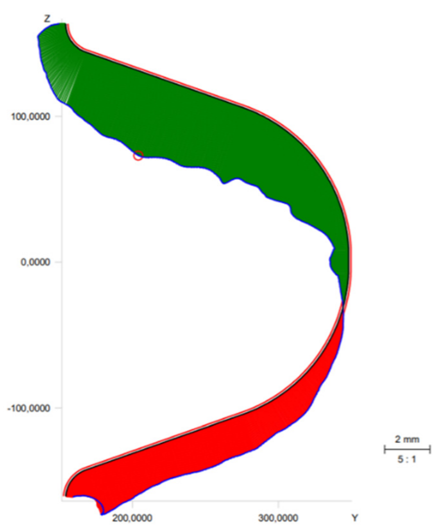

Figure 9: Thickness profile of the second 400 MHz.

The internal profile of the second cavity were evaluated (Fig. 10) and the results were that in correspondence of the first iris the cavity had a larger diameter respect to the standard requested, while at the other points measured in the first half cell and in the second half cell the cavity presented a smaller diameter. This effect could be explained as for the circularities with the anisotropic stress relief after each thermal annealing. Moreover, the second half cell was spun applying a lower force to avoid cracking of the thin walls, and the effect can result in a negative displacement from the ideal profile.

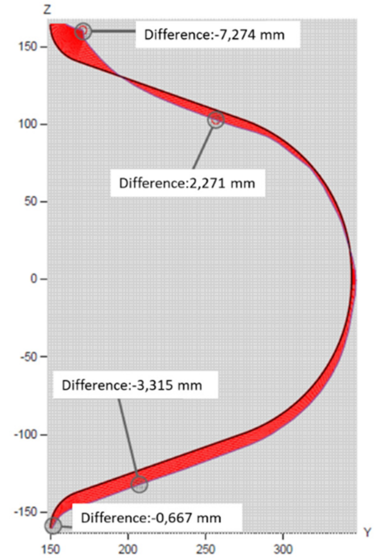

Figure 10: Internal surface profile of the second 400 MHz.

CONCLUSIONS AND COMMENTS

The two seamless 400 MHz copper cavities were produced by spinning, the first prototype presents several cracks on the iris region, the second prototype has two small cracks on the cut-off region. Three thermal annealing were the minimum to complete the cavity with a good material spinnability. The feasibility to produce a 400 MHz seamless cavity was demonstrated, further developments are necessary to avoid cracks, increase the geometry accuracy and the internal surface quality as for example optimizing the annealing procedure (acting on temperature and time) and inserting different intermediate mandrels to reduce the distance between the cavity wall and the mandrel surface during each step of spinning.

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REFERENCES

[1] C. Pira, Oscar Azzolini, Giorgio Keppel, Silvia Martin, Fabrizio Stivanello, Seamless accelerating cavities, Accelerating news Mar 2019.

[2] W.V. Delsolaro, Thin film research: CERN experience and possible future applications (TESLA Technology Collaboration (TTC) Meeting, Milano, Italy 2018)

[3] V. Palmieri, SEAMLESS CAVITIES: the most creative topic in RF Superconductivity (Workshop on RF Superconductivity, Abano Terme (Padova), Italy 1997)

[4] O. Music, J.M. Allwood, K. Kawai, A review of the mechanics of metal spinning, Journal of Materials Processing Technology 210 (2010) 3–23.