QUALITY CONTROL AND PROCESSES OPTIMIZATION FOR THE EXFEL SUPERCONDUCTING CAVITIES SERIES PRODUCTION AT ETTORE ZANON SPA

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Abstract

The construction of the European XFEL forced the first mass production of Niobium bulk SRF cavities.

In this context Ettore Zanon S.p.A. built a fully new facility designed to produce four fully treated and He tank equipped cavities per week, ready to be tested at DESY. The facility already reached the foreseen production rate.

The guarantee of the highest quality of the resonators produced requires a very strict quality control plan. At the same time, the requirements of the industrial production in terms of time, cost and productivity must be satisfied. As a consequence processes must be standardized and working times optimized.

In the following, after the description of the production facility, we would like to highlight and discuss the strategies and arrangements adopted in the various critical fields (clean room, vacuum, etc.) to ensure the foreseen results.

Moreover correlation between cavities performances and production cycle parameters will be investigated and discussed.

INTRODUCTION

Ettore Zanon S.p.A (EZ) has overcome the ramp-up phase and it has now entered the full production phase [1, 2]. A complete new facility has been built to fulfill the needs of SRF cavities production. Clean environment for operation is provided by a 400 m^2 clean room constituted by an ISO7 and an ISO4 areas (classification referred to ISO14644-1 norm). ISO7 is used for the assembly of cavities before welding, US cleaning of components and materials, chemical treatments (both external and internal) and ethanol rinsing. ISO4 instead provides a cleaner environment for high pressure rinsing, assemblies of flanges or accessories and final leak checks. These last are made using three pumping units, two built as slow pumping-slow venting (SPSV), located on the outside.

The external area is the location for a high temperature vacuum oven (800 °C), capable of treating four cavities at a time, two low temperature (120 °C) baking stands, built to treat two resonators each, the semi-automatic Helium tank welding equipment, pressure test safe room and the cavity tuning machine, together with stations for every type of control made on the cavities (visual, dimensional, RF and leak tightness). See ref [3], for more details.

The exact distribution of the operations with respect to the production cycle is given in Figure 1.

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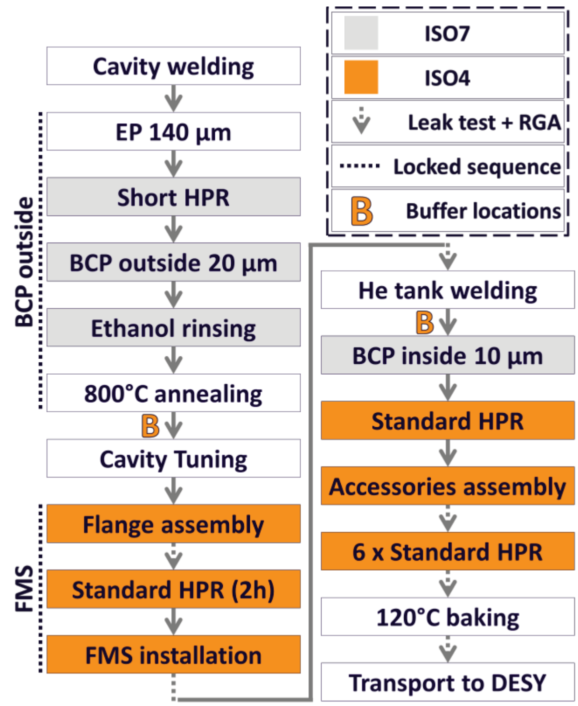

Figure 1: EXFEL Cavity treatment cycle.

CAVITY PROCESSES OPTIMIZATION

The production cycle is based on DESY's specifications and follows the path named "BCP Flash" represented in its main outline in Figure 1 [4].

The production ramp-up allowed EZ to identify and analyse critical steps, strategic resources and bottle necks. The main issues were determined to be operations scheduling, Ultra-Pure Water (UPW) management and SPSV system.

Organization

Timing is a very sensitive point: the production cycle has quite rigid constraints, mainly regarding delays between steps and pressure to be reached for the leak tests. In order to combine all the operations, a careful and detailed scheduling is required. To maintain the actual throughput, 24 to 28 cavities need to be under treatment at the same time, thus planning becomes critical also because of the large number of cavities in processing. The result is a "standard-week" plan, in which all the

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operations to have four finished pieces are featured and kept constant week by week.

Three main locked sequences of operations are present in the whole treatment cycle (see Figure 1). The most critical sequence is the one from inner 10 µm BCP to 120 °C baking. Nine to fifteen hours of drying after each High Pressure Rinsing (HPR) and two leak tests (maximum acceptable pressure $1\cdot10^{-6}$ mbar) are requested, taking about four days of work to be done. To overcome the limits of this sequence a two-shifts work organization (16 working hours per day) has been implemented. Moreover, this sequence can be effective and suits the production needs only if the 6xHPR is done during night time.

The ramp-up phase highlighted with emphasis the need for some cavity buffers along the line in order to minimize the loss of productivity in case of any inconvenience occurred during the production. Buffers are found to be more useful before the locked sequences, e.g. after the 800 °C annealing and after the He tank welding (see Figure 1).

Ultra-pure Water

One of the most important resources is Ultra-Pure Water (UPW), which is used in most of the production steps. Lack of water can result in serious delays of the operations compromising the weekly production rate.

HPR stands are the most UPW consuming utilities, using about 1 m^3/h each during the functioning; HPRs take place after critical steps (e.g. inner BCP, accessories mounting, etc.) so they cannot be stopped without the need for some steps to be repeated.

To assure the continuity of the operations, the storage capability of the 3 m^3/h UPW production plant has been increased to 9 m^3 and the scheduling arranged in order to minimize the peaks of UPW consumption. Moreover, an automatic control system has been implemented, distributing different priorities to the process infrastructure. With this arrangement, in the remote case of water lack, less sensitive equipment (e.g. US cleaning tool) will be stopped while the most critical ones (e.g. HPRs) will be continuously fed.

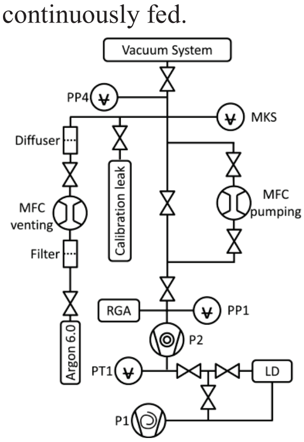

Figure 2: SPSV layout. With reference to the above: PP1 and PP4 are UHV gauges, PT1 is a Pirani gauge and MKS is a differential gauge.

SPSV

Another investigated and optimized unit is the Slow Pumping Slow Venting system (SPSV), used for all the leak tests made after the inner BCP. This specific configuration is required for these last steps of the production cycle because of his capability of maintaining the highest cleanliness standard of the inner surface. In fact, according to previous studies [5], pumping down and venting in the 10^3-10^0 mbar range must be done carefully avoid particle contamination of the inner surface that could compromise cavity performances (field emission, multipacting). SPSV is built to control the gas flow and thus the pressure trend through Mass Flow Controllers (MFCs) in these critical moments. Its layout is shown in Figure 2. Having at the beginning of activities only one SPSV unit available, this allows maintaining only a single cavity in vacuum after inner BCP. The final locked sequence requires two leak tests using the same system, so it is not possible to start it for two cavities at the same time, setting a upper limit to the weekly production rate.

The sequence of operations proposed by the SPSV supplier has been proven to be unsuitable in order to avoid pressure bumps and thus particles movement inside the cavities. A thorough optimization work was done on the valves opening sequence and the flow rates resulting in smooth pressure trends as shown in Figure 3.

On the base of the experience made on the first system EZ has built in-house a second SPSV unit with some technical improvements (diffuser build up and position, slow pumping line construction). This new SPSV will help to increase the production rate or to have a backup unit for any delay in cavity processing.

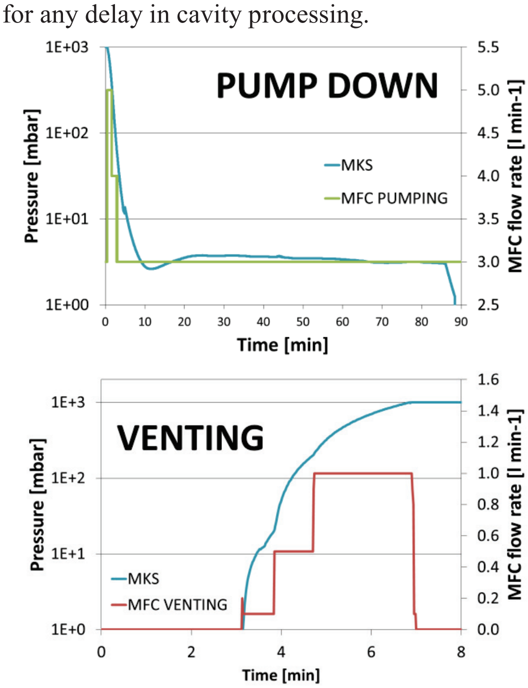

Figure 3: SPSV pressure and flow rate (10^3-1 mbar).

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QUALITY CONTROL

The production rate reached by EZ with the arrangements described above must be accompanied by a meticulous quality control of the parameters that can be involved in the cavity performance. The most sensitive part of the cavity is the inner surface, thus everything that goes in touch with it (water, cleanroom environment, pumping systems, ethanol) must be carefully checked.

One of the principal control techniques is the residual gas analysis (RGA), especially to detect hydrocarbons pollution. It is used throughout the whole cavity life (each time the cavity is evacuated, see Figure 1) and could be used also to evaluate the cleanliness of the fluids (e.g. gases or water) in contact with the cavities' surface.

Purity of gases (Argon, Nitrogen and Helium) used both in clean room and in the vacuum systems is obtained starting from high quality products (5.5 N) and adding filters series at the point of use (hydrocarbons, water and oxygen; particles above 40 nm, plus a 20 nm all metal on the pumping units). UPW is checked measuring resistivity, Total Organic Carbon (TOC) and filtered to eliminate particles (> 20 nm). UPW resistivity is controlled at the inlet of every point of use and must be 18 MΩ·cm. On line control of particles in the UPW loop is active using a liquid particle counter, while a sampling procedure is done for checking particles in the HPR. The maximum limit for the TOC during HPRs is 4 ppb. Figure 4 shows a typical trend of resistivity and TOC during a 6 x standard HPR.

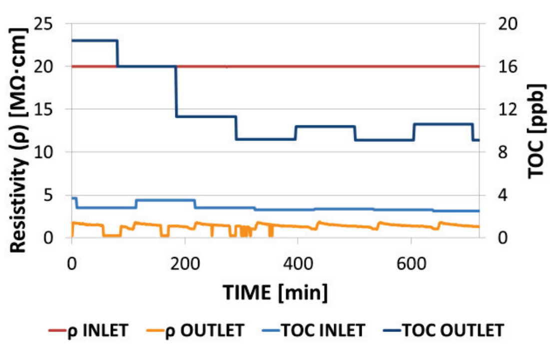

Figure 4: HPR recording with resistivity (ρ) and TOC.

The quality of the cleanroom environment is controlled as prescribed by the ISO14644-2 norm with a particle count, air speed and dust test at least every six months.

All the components that have to be assembled to the cavity must be blown with ionized nitrogen inside the ISO4 cleanroom. The number of particles resulting from this operation is strongly affected by the "human factor", i.e. much depends from the care that each operator uses during this step: the better the operator will be trained and will respect the operative instructions, the better the quality standard will be. Precise and complete procedures and checklists for every type of assembly are useful tools to reach this objective.

A point that is worth to be mentioned regards the ethanol rinsing. During some tests aimed to determine the amount of sulphur dissolved in ethanol (definition of optimized time between refills), it was realized that the plasticizer contained in the PVC tubes in use (Bis(2-ethylhexyl) phthalate, known as DEHP) is soluble in alcohol, giving a possible source of contamination of the internal surface. The presence of this compound was determined by the use of an FTIR spectrometer as can be seen in Figure **5**. RGA performed on the 800 °C oven (step after ethanol rinsing) shows no significant sign of contamination from DEHP. As a precaution, PVC piping are replaced with PE ones, where no plasticizer is present.

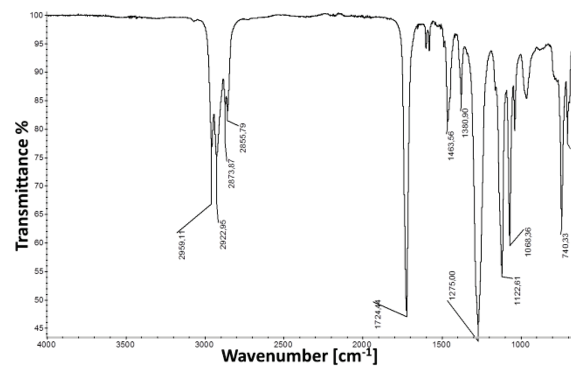

Figure 5: FTIR spectra of DEHP found in ethanol.

CAVITY PERFORMANCE ANALYSIS

Data collected from the strict quality control are stored in a database [6]. Those data are analysed in order to determine correlations between process parameters and cavity performances and are used to integrate the usual quality control procedure applied in all treatment steps.

During ramp-up, many cavities did not follow the standard production path: as a result it is difficult to correlate those cavities' performances with the treatments. However, those cavities allowed EZ personnel to gain an experience and knowledge of what can deteriorate the resonator performances and how to repair certain kind of damages.

From the collected data, possible influences on cavity performances due to last surface treatment steps (considered more critical) are investigated.

Until now, we have no evidence of possible direct influence of one specific process on both accelerating field and Q.

As an example, the ISO4 drying after the last 6 x standard HPR was studied as it is the last treatment with the cavity open. The influence of drying operation was analysed collecting all available cavity performances in term of Q values at low accelerating field (4 MV/m) measured during the cold RF vertical test at DESY. They have been plotted respect to the drying time and the drying location in ISO4. Results are shown in Figure 6. Even if the statistic is still limited to 56 cavities, the drying time (between 9 and 15 hours) and the drying location (with respect to absolute filter position in ISO4) do not influence the final cavity performances.

The dependence of the used HPR for the last 6 x standard HPR has been investigated (HPR1: ISO7/ISO4; HPR2: ISO4). Also in this case, no meaningful influence has been highlighted, as shown in Figure 6 (bottom plot).

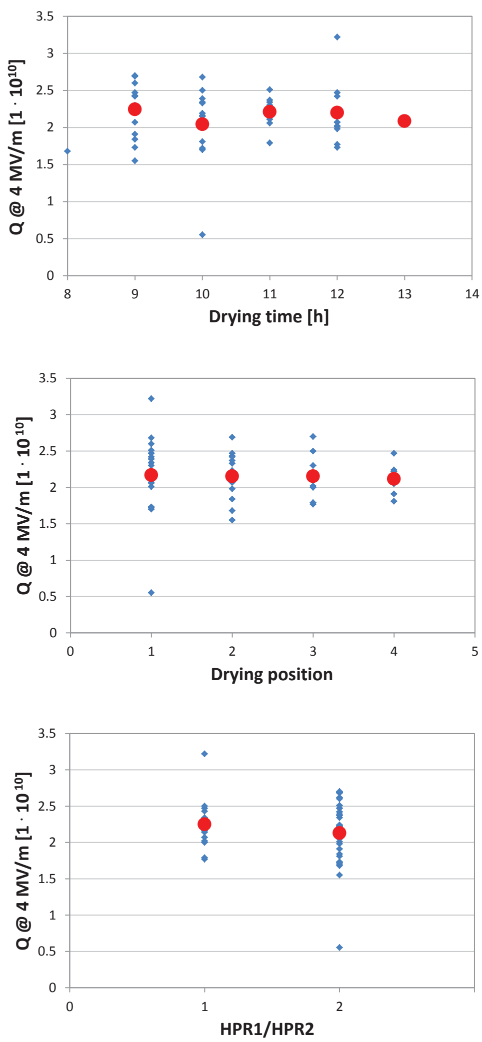

Figure 6: Influence of the last operations in ISO4 (drying and HPR) on the series cavity performances (Q). Q @ 4 MV/m measured for each cavities (blue), average value (red).

CONCLUSIONS

Cavity production infrastructure is now completed and produces about 4 cavities/week.

Bottle necks and critical points had been evaluated and corrected with proper actions as increased UPW storage, seconds SPSV unit, and cavity buffer creation.

Up to now more than 100 cavities had been mechanically constructed and more than 70 already passed through the treatments cycle.

While up to now, the number of studied cavities does not represent a statistically significant batch, we expect, with the production up and running, to be able to determine some correlations and to gain a deeper knowledge of the processes, as soon as the treated cavities will be more.

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