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ESS MEDIUM BETA CAVITIES STATUS AT INFN LASA

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Abstract

INFN Milano contributes in-kind to the European Spallation Source ERIC (European Research Infrastructure Consortium) Superconducting Linac supplying 36 cavities for the Medium Beta section of the proton accelerator. The production has reached completion, being all the cavities mechanical fabricated, BCP (Buffered Chemical Polishing) treated and, for most of them, also qualified with vertical test at cold. In this paper, we report on the results and lessons learned and the actions taken both for quality control managing and recovery of the few cavities that did not reach the project goal after the first qualification test.

INTRODUCTION

The European Spallation Source (ESS) ERIC will be the most intense neutron source in the world. To generate such high flux of neutrons by the spallation process, an intense proton beam (2 GeV, 62.5 mA, 2.56 ms pulse length and 14 Hz repetition rate) will be generated by a Superconducting Linac.

INFN LASA is providing, as part of the Italian In-Kind contribution, the 36 cavities for the Medium Beta section (β= 0.67) [1–3], that will boost the beam energy from 216 up to 571 MeV before the injection into the High Beta accelerating section.

As a preliminary activity to the series production required to provide the cavities to ESS, we started a review of the original cavity design aiming to improve the cell-to-cell coupling and the High Order Mode (HOM) extraction capability. For this activity, we consider both the electromagnetic design as well as the mechanical properties of the cavity. The outcome was a new design of the cavity with dedicated half cell shapes for the terminal cells of the cavity. From an electromagnetic point of view we achieved an increase of the coupling factor by 1.55 % with a small increase (+7 %) in the ratio E_{peak}/E_{acc} and a modest reduction (−6 %) of the R/Q parameter [4].

PROTOTYPE CAVITY

To validate the concepts studied in the design, a prototype cavity MB001 was built including, already from this phase, all the requirements necessary for a later series production. In particular, we considered the implications given by the adherence to the European Pressure Equipment Directive (PED) art. 4.3, i.e. pressure test and recording of "best engineering practice" and consequent certifications.

The prototype was firstly tested not jacketed at LASA reaching very good results [5]. This induced ESS to include MB001 cavity, after its integration in He-tank, into the ESS

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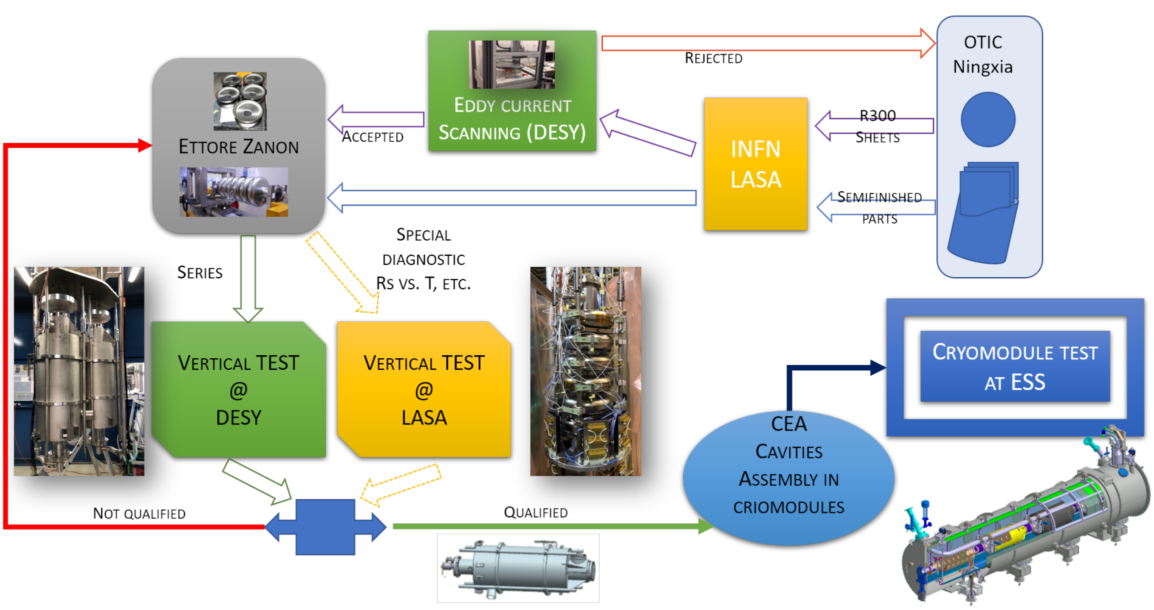

Figure 1: Cycle from Nb sheets to qualified cavity. Different laboratories (INFN, CEA, DESY, ESS) and vendors (Niobium and cavity) are involved in this complex workflow.

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MB demonstrator (M-ECCTD) together with three CEA cavities [6]. The very good results of our prototype also during the operation in the module gave the start to the series production.

CAVITY WORKFLOW

The ESS MB cavities fabrication cycle is sketched in Fig. 1. A detailed description of this cycle has already been done in previous works [7]. Here we want only underline the main steps.

All the Nb sheets received from the vendor were Eddy Current scanned at DESY and no inclusions were found. With these sheets, the cavity is mechanically assembled and chemically treated. Being the performance not extremely demanding, the BCP process was chosen: 200 µm for the "bulk" treatment and 20 µm for the "final" one [8, 9].

After the "bulk" chemistry, the cavity is dehydrogenated in vacuum at 600 °C for 10 h. Afterwards, the cavity is tuned to the proper frequency and field flatness before being integrated into the He-tank. Before the preparation for the Vertical Test at cold, the He-tank is tested at 1.5 bar (w.r.t. atmospheric pressure) to assure the compliance with the Pressure Equipment Directive (PED) art. 4.3 requirements.

If all the controls are passed, the cavity is prepared for the test and sent to DESY. If also the RF test at cold is passed, the cavities are handed over to ESS and delivered to CEA for integration into modules.

QUALITY CONTROL AND QUALITY ASSURANCE

A dedicated QC/QA (Quality Control/Quality Assurance) procedure follows each step of the cycle from sheets to finished cavity, to test and finally to delivery to CEA. Special tools (see Fig. 2) have been developed for documents approval as well as for monitoring "key" parameters to assure a proper surveillance of the production process [10].

Figure 2: Screenshot of the tool developed for controlling documents upload and approval status.

Moreover, for each cavity we have about two hundred documents that track the main steps from the raw material to the cavity delivery to CEA. These documents are the basis for the handing over process of the cavity to ESS [11].

VERTICAL TEST RESULTS

The cavity qualification process is done at DESY where the cavities (usually in pair) are tested in the upgraded AMTF Vertical Test Facility (see Fig. 3) [11, 12] .

Figure 3: DESY cavity inserts. Pair of cavities can be tested even in different configuration (naked or jacketed).

The ESS requirements for cavity qualification to be demonstrated at 2 K are:

- E_{acc} = 16.7 MV/m and a quality factor $Q_0 = 5{\times}10^9$
- monopole HOM at least 5 MHz away from machine lines
- separation of at least 0.75 MHz from 5/6 π to π mode.

Up to now, twenty eight cavities have been qualified and delivered to CEA for integration into the cryomodules. Figure 4 shows their Q_0 vs E_{acc} plots. The perfomances of all cavities are well above the specification in term of accelerating field and quality factor.

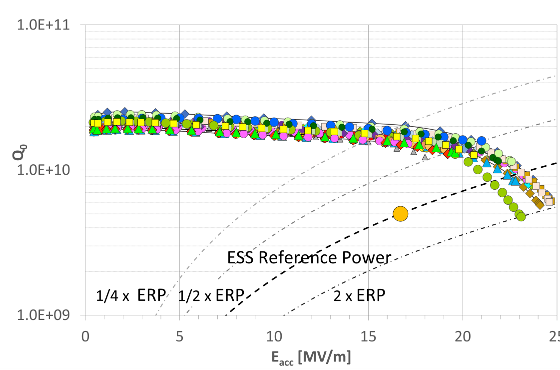

Figure 4: Power rise of the ESS MB qualified cavities. The yellow dot shows the ESS requirements for qualification. ERP (ESS Reference Power) indicates cryogenic consumption at the nominal ESS parameters. The Q_0 of the INFN LASA MB cavities are well above this requirement.

If the qualification accelerating field is taken as reference, Fig. 5 is the histogram of the corresponding Q_0 at goal. Clearly, the MB cavities have quality factors between two and

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three times higher than the requirements and this translates in a possible operation of the MB section of the linac at reduced consumption w.r.t. design values.

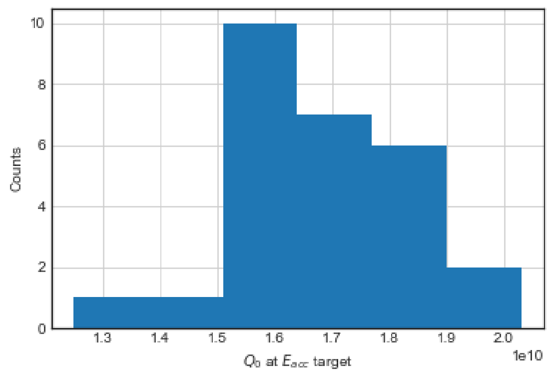

Figure 5: Histogram of the Q_0 measured at the nominal field of 16.7 MV/m. All the cavities have values nearly three times higher than the ESS target.

For these qualified cavities, 89 % reached the ESS goal at the first VT test, 7 % needed a further HPR treatment and 4 % where recovered by a flash BCP treatment. The final limitation of all these cavities is a quench and no or very low field emission levels.

Special cavities that need detailed diagnostic are also tested at INFN LASA. Second sound and fast thermometry are used for quench localization, photodiodes and scintillators for X-ray detection and real time X-ray acquisition for emitted electron energy measurements [13].

CAVITY RECOVERY

The recovery of cavities that have not reached their qualification goal at the first test is an important part of the activity we have done in the past year. Among the cavities qualified so far, some of them needed to be retread mainly to remove field emission and soft multipacting barriers [14].

To address these issues probably due to some contamination, we revisited and further optimize the HPR head, by improving the jets pattern on the cavity walls. A clear example of the efficiency of the new HPR is represented by cavity M006.

Figure 6 reports the cavity performance before (blue dots) and after (yellow dots) the new HPR. During the first test, cavity performance was limited by a strong multipacting barrier between 10 and 15 MV/m (not possible to condition) and by huge field emission at higher accelerating fields. This is confirmed looking at the X-rays measured during test and shown in the same plot. After the new HPR retreatment, a soft multipacting incurred during the test that was easily conditioned. Moreover, no field emission was measured at all. For completeness, Fig. 6 reports also the first test (orange dots) of this cavity as naked (before its integration into the He-tank) [12]. Both tests (before and after He-tank integration) show large multipacting not conditionable as well as field emission, but the starting of the MP barrier happens at lower accelerating gradient for the naked cavity (8 to 12 MV/m) w.r.t jacketed one (11 to 14 MV/m). This is probably due to the fact that the He-tank integration process implies a further final BCP (about 20 µm) followed by its long HPR that changed slightly the inner cavity surface conditions.

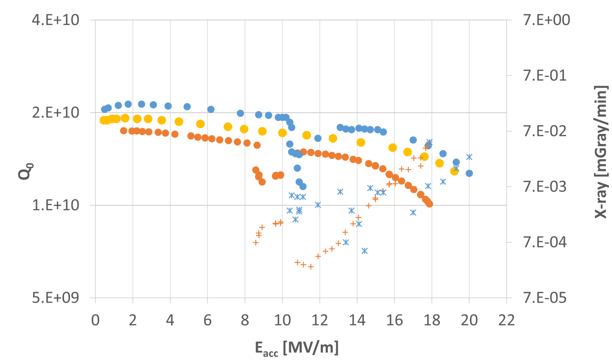

Figure 6: M006 tests: naked cavity (orange), after integration (blue) and after HPR retreatment (yellow)

Concerning the remaining eight cavities needed to complete the set of cavities required for finalizing our contribution to ESS, activities are on going to recover them to full specifications. These cavities have typically very good Q_0 (well above 1.5×10^{10}) but their quench field does not yet reach the ESS goal.

CONCLUSION

INFN LASA is strongly committed to the qualification and delivery of the Medium Beta cavities for the ESS Superconducting Linac. All the cavities so far ready for integration into cryomodules at CEA-Saclay have performances well above the specification, in particular in term of Q_0.

As part of this activiy, we have recovered the performance of some cavities by an improved HPR head. Meanwhile, we are also progressing in the activities necessary to take the remaining cavities to ESS specifications.

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