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RECENT UPDATE ON ESS MEDIUM BETA CAVITIES AT INFN LASA

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Abstract

The INFN LASA contribution to the European Spallation Source ERIC (European Research Infrastructure Consortium) Superconducting Linac is focused on supplying 36 cavities for the Medium Beta section of the proton accelerator. Twenty eight cavities have been fully qualified and delivered to CEA for integration into the cryomodules. We present the status of the activities dedicated to completing our contribution both by applying alternative surface treatments with respect to the series vertical BCP and by procuring new cavities.

INTRODUCTION

The European Spallation Source (ESS) ERIC will be, once in operation, the most intense neutron source in the world [1]. ESS make use of a superconducting linac section to accelerate a 62.5 mA proton beam to an energy of 2 GeV. This powerful beam will then be delivered to a target station for producing a neutron beam by the spallation process [2].

The 5 MW beam will be pulsed at 14 Hz with each pulse being 2.86 ms long. This long pulse operation is a real challenge and, to achieve this and save in cost, superconducting cavities are required and they need to operated at high accelerating gradient.

INFN Milano - LASA contributes, as part of the Italian In-Kind contribution, to the Medium Beta ($\beta = 0.67$) Section of the ESS Superconducting Linac with thirty-six cavities that will boost the proton beam energy from 216 MeV up to 571 MeV [3, 4]. Table 1 reports the key parameters of the INFN MB cavities. Ref. [5] reports a discussion on the rationale for the cavity electromagnetic and mechanical parameters selection and the path towards the final design of the resonator.

In this paper, we briefly present the status of the project and then we will report on the results of the cavities tested so far. A dedicated section is reserved for discussing ongoing activities related to the qualification of the last batch of cavities needed to complete our contribution.

PROJECT STATUS

The ESS Medium Beta cavity production is now in a well advanced phase.

The description of the production process and of the related Quality Assurance (QA) and Quality Control (QC) steps have been already presented in previous papers (see [6] for the most recent update).

Here, we only remind that the production of the cavities is divided, also for QC, in five Acceptance Levels (AL) namely:

- AL1: Cavity after Electron Beam welding
- AL2: Cavity Bu˙ered Chemical Polished and RF tuned
- AL3: Cavity integrated and ready for Vertical Test
- AL4: Cavity successfully tested in cryogenic operation
- AL5: Cavity delivered to CEA for integration into cryomodule

Twenty eight cavities have successfully reached the final step AL5 and are now integrated at CEA in the cryomodule named CM01 to CM07, hosting four cavities each.

In Fig. 1, we report the result of the qualification test i.e. the quality factor (Q_0) versus the accelerating gradient (E_{acc}) measured at 2 K at the AMTF facility in DESY [7].

All the qualified cavities have a very high Q_0 in the region of 2×10^{10} at low accelerating field. Even at the reference ESS goal gradient of 16.7 MV/m, the quality factor is well above 1×10^{10} With respect to the ESS Reference Power (ERP), the performance of the Medium Beta cavities allow operation between one half and one fourth of the foreseen nominal cryogenic power.

Figure 2 reports the measured X-ray level reached during the previous mentioned test versus the accelerating field for the detector placed below the cavity. A second detector is placed on top of the cryostat during operation [8]: this

Table 1: ESS Medium Beta Cavities Main Parameters

Parameter	**Value**
R_{iris}	50 mm
Geometrical β	0.67
π-mode Frequency	704.42 MHz
Acc. length	0.855 m
Cell-to-cell coupling k	1.55 %
π-$5\pi/6$ mode sep.	0.70 MHz
Geometrical factor G	198.8 Ω
Optimum beta, β_{opt}	0.705
Max R/Q at β_{opt}	374 Ω
E_{acc} at β_{opt}	16.7 MV/m
E_{peak}/E_{acc}	2.55
E_{peak}	42.6 MV/m
B_{peak}/E_{acc}	4.95 $\frac{mT}{MV/m}$
Q_0 at nominal gradient	$>5\times10^9$
Q_{ext}	7.8×10^5

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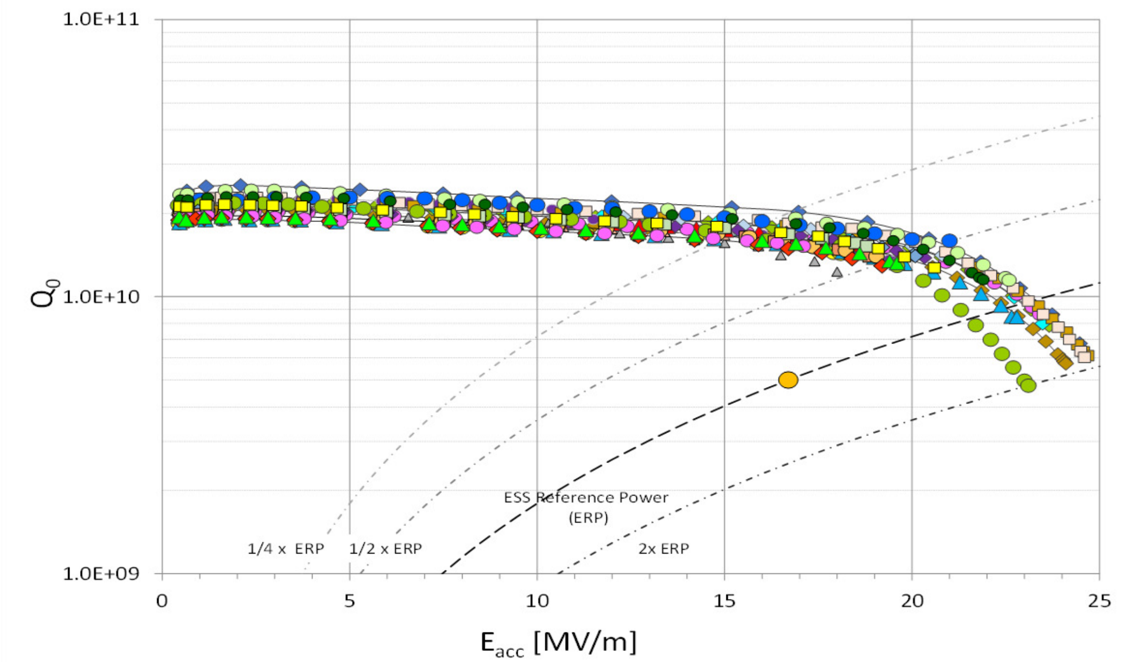

Figure 1: ESS Medium Beta Cavities qualification power rise at 2 K, the nominal working temperature. ERP corresponds to the cryogenic power consumption at the ESS goal of $5{\times}10^9$ at 16.7 MV/m.

detector usually measures lower radiation level w.r.t. the lower one and hence it has not be considered in this analysis.

The lower orange band in the plot corresponds to the detection limit of the apparatus at DESY. The Vertical yellow region is the region where it is possible to have multipacting (MP) activity [9]. Finally the vertical line shows the ESS reference gradient. Besides few cavities, all the qualified cavities shows no or very limited activity.

The only few cavities that showed X-ray emission during test had, anyhow, radiation level acceptable for operation in the Linac and were accepted by ESS. It is also worthwhile to mention that only one cavity showed radiation consistent with a soft MP activity in the resonator during test and that could be easily processed away.

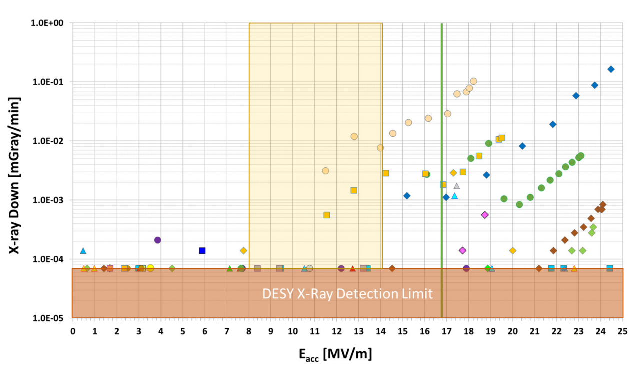

Figure 2: ESS Medium Beta Cavities X-ray emission during power rise. "Orange" band represents the threshold limit of the detection system while the "Yellow" area indicates the MP region of the MB cavity.

NEW CAVITY PROCESSES

A big e˙or t is on-going to qualify the low performance cavities. We deeply analyzed all the main steps relative to the production process at the company, searching for possible critical issues. A first successful result was obtained designing a new head for the HPR system that allowed a better cleaning of the cell steep wall, leading to a suppression of the field emission and, consequently, of the full recovery of one cavity (see ref [6]). On other cavities, HPR was not as successful as on the previous mentioned cavity. The performance of the cavities not yet qualified is reported in Fig. 3. The plot shows that we have two kind of low performance cavities, the first limited by E_{acc}, the second limited both by E_{acc} and Q_0, with a significant Q drop already at low gradient.

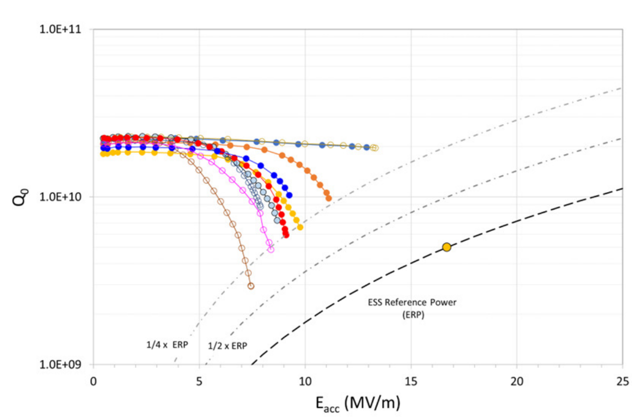

Figure 3: Power rise for ESS MB cavities that do no reach specifications.

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All low performance cavities are not a˙ected by field emission. For the low E_{acc} and low Q_0 cavities, the Q drop already at low accelerating fields is a hint of a consistent dissipating e˙ect without radiation. An hypothesis raise after results obtained during the inner optical inspection performed on low performance cavities that revealed the presence of grooves, mainly distributed along the cell steep wall and on the iris areas. We did several analysis on cell surface, also using replicas that we analyzed by 3D optical microscope. Models presented in literature [10, 11] attributed to these features a dissipation mechanism compatible with our measurement. To overcome this issue, we started to develop several recovery strategies, mainly trying to improve BCP process parameters (see [12]) and also investigating possible other surface treatments that might reduce the final surface roughness like Electropolishing (EP) and rotational BCP.

Electropolishing - Retreatment of Cavity M024

Cavity M024 barely reached 8 MV/m with a significant Q-drop in its first vertical test, as naked cavity, performed at the INFN LASA test facility. In order to improve its performance, the cavity underwent a new surface processing procedure, based on EP as main surface treatment. The goal of this treatment is to exploit the smoothing e˙ect of EP [13] so to get rid of - or at least mitigate - the many geometrical defects which emerged on the cavity surface after the bulk BCP treatment.

The EP plant at the vendor was already optimized for the treatment of PIP-II 650 MHz prototypes, whose shape and size is similar to that of the ESS Medium Beta cavities. The main upgrades were the installation of Aluminium enlargements on the cathode in correspondence with cavity equators, to locally increase the current density, and the installation of an additional external water chiller to control the temperature increase due to the EP reaction at irises and beam tubes, if needed. In the case of ESS cavity re-treatments, a 23 °C temperature set-point on cavity external surface has been chosen to drive the EP reaction to equilibrium. Before the EP process itself, a polarization curve vs V was acquired to verify that the process parameters are set so to operate in the current plateau regime needed for benefit the smoothing e˙ect of EP.

Cavity M024 underwent a 100 µm total EP removal. Applied voltage was 17 V, which resulted in an average removal rate of 0.17 µm/min. At the end of the treatment, the cavity was visually inspected to check the surface finishing. Being this satisfactory, the cavity proceeded to the following processing steps. At first, a 10 hours long 600 °C annealing in UHV conditions so to get rid of the hydrogen introduced by the treatment. Afterwards the cavity was tuned to goal frequency and field flatness. A final 10 µm EP was performed in the "cold" regime, namely with a 12 °C temperature set-point on cavity surface, with the intent of increasing surface smoothness. In this case, a 0.09 µm/min average removal rate is obtained. This data are in line with the one obtained during the treatment of PIP-II LB prototype cavities [14].

The first indications from the vertical test of cavity M024 are encouraging in term of accelerating field and quality factor but further studies are still necessary for a final assessment.

Rotational BCP

Seven out of ten not yet qualified cavities have been already integrated into the He-tank. Integrated cavities have the additional constrains that there is no possibility to tune them and we have a marginal frequency budget to respect the frequency goal set by the project.

For this reason, it is important to identify a solution capable to recover the cavity with the tank, for cost e˙ectiv eness and time sparing. To proceed along this way, we have sent cavity M028 to Argonne National Laboratory (ANL) that has developed a horizontal BCP treatment. This treatment, di˙erentl y from the vertical BCP process used during the series production, should allow for a more uniform removal with possibly less topological features on the surface.

M028 was sent to ANL in Summer 2021 and treated by removing 25 µm as measured by Ultra Sound technique after the process. The cavity came back to Italy and prepared for vertical test. The cavity will be tested at CEA by the end of June 2022.

New Cavity Production

To mitigate possible further delays, we have also started the production of four additional cavities that will be treated with EP process to avoid possible contribution from topological imperfections. All the cavities have been welded and ready for EP bulk treatment.

Two of the cavities will be tested before proceeding with integration to validate the new processing cycle. Afterwards, all the cavities will be integrated and prepared for the qualification test at DESY before their delivery to CEA, foreseen for the end of 2022, for integration into the cryomodule.

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CONCLUSION

The Italian In-Kind contribution to the ESS project with the Medium Beta cavities is on going. Twenty eight out of thirty six cavities have been delivered for integration into the cryomodules.

An intense activity, devoted to the qualification of the final eight cavities needed to complete the contribution, is progressing along di˙erent paths aiming to recover both integrated cavities as well as unjacketed cavities.

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