ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPA006

ACTIVITIES AT INFN LASA ON ESS MEDIUM BETA CAVITIES

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Abstract

To complete the Italian In-Kind contribution to the European Spallation Source Superconducting RF Linac, we are working on the qualification of the last eight missing cavities. To achieve this, we are proceeding with reprocessing of not yet qualified cavities and, as a mitigation, we are constructing at the vendor four more cavities. In this paper, we report on the actual status of both of these activities with the most recent results.

INTRODUCTION

The European Spallation Source (ESS) ERIC will be, once in operation, the most intense neutron source in the world [1]. ESS is based on a SuperConducting (SC) Radio Frequency (RF) linac section to accelerate a 62.5 mA proton beam from an energy of 90 MeV to an energy of 2 GeV, using different typologies of cavities such as spoke and Medium and High Beta elliptical. The proton beam will then be delivered to the target station for producing the neutron beam by the spallation process [2].

The 5 MW average power proton beam will is distributed in 14 pulse per second, each pulse being 2.86 ms long. This long beam pulses require operation with superconducting cavities in order to achieve the project parameters while preserving in cost. Moreover, the SC cavities need to be operated at at high accelerating gradient to reach the needed energy in the foreseen accelerator footprint.

INFN Milano - LASA leads the Italian In-Kind contribution to the Medium Beta ($\beta = 0.67$) Section of the ESS Superconducting Linac by providing the thirty-six cavities necessary to constitute the nine modules, assembled at CEA, that boost the proton beam energy from 216 MeV up to 571 MeV [3, 4]. These cavities have been designed at INFN LASA [5] starting from the electromagnetic, through the mechanical desing. The choice of the optimal parameters have been done to satisfy the project parameters and to cope with the interfaces needed for the cavity installation in the cryomodule.

This paper presents an update on the cavity production status with dedicated emphasis on the actions performed so far to recover low performance cavities, the production of new resonators necessary to complete the In-Kind contribution and with an outlook to possible production of spare cavities.

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ESS MEDIUM BETA CAVITIES PRODUCTION STATUS

The production of the ESS Medium Beta cavities is based on a scheme inherited from our activity for the industrial production of the XFEL SRF cavities.

INFN has developed strict prescriptions for the cavities production and organized a Quality Control and Quality Assurance plan to follow the whole cavity production [6]. Given the ESS goal, we have decided to treat the cavities with a Buffered Chemical Polishing (BCP) process both as bulk and as final treatment. The latter is the last process needed for preparing the cavities for the Vertical Test at cryogenic temperature for cavity qualification. To cope with the high test throughput required by the project, the majority of the qualification tests have been done at DESY, in the AMTF infrastructure [7]. Only for specific cavities, we have used the LASA infrastructure that, even if it can not withstand the series test rate, it is equipped with advanced diagnostic that allow identification of quench and field emission sources that might limit the cavity performances.

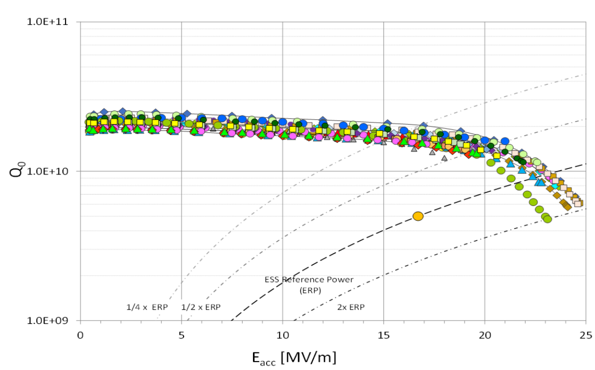

Figure 1: ESS Medium Beta Cavities qualification power rise at 2 K, the nominal working temperature. ERP corresponds to the cryogenic power consumption at the ESS goal of 5×10^9 at 16.7 MV/m.

Twenty eight cavities had successfully overcome the ESS specifications and they had been assembled into cryomodules at CEA that then have been transferred to ESS for tests in preparation to installation in the Linac [8, 9].

Figure 1 presents the qualification curves (Q_0 vs E_{acc}) for these cavities, as done at 2 K. All of them have quality factor (Q_0) at ESS E_{acc} goal well above specifications (E_{acc} = 16.7 MV/m at $Q_0 = 5 \times 10^9$).

Indeed, considering the delivered cavities, the Q_0 values are distributed as reported in Fig. 2. The measured values are

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between two and four times higher that the ESS specification, i.e. with reduced static cryogenic consumptions.

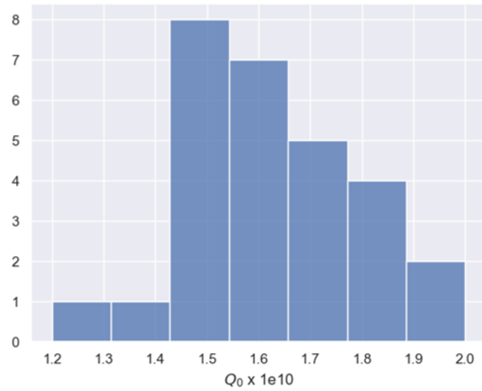

Figure 2: ESS Medium Beta Cavities Q_0 values as measured during qualification test at the goal E_{acc} . Being the Q_0 reference value 5×10^9, the measured values are between two and four time this value

CAVITY RETREATMENTS

The qualification of the missing cavities needed to complete the Medium Beta section of the ESS linac has been our main focus in the past year.

As already presented [10], we reviewed the whole production process identifying two area of improvements: High Pressure Rinsing and BCP treatment. The former was optimized to properly cover the ESS large cell with the steep wall (given by the low beta geometry) while the latter was deeper investigated because in cavities that not reached the ESS requests due to Q drop at low gradient without field emission. Indeed, we observed deep grooves on the inner cell surface, particularly in the region starting from the equator towards the cell inclined wall. Dedicated fluid dynamics simulations [11] show that this features might be caused by bubble generated during the BCP process due to the low speed of the fluid in this region of the cavity.

Based on this information, we decided to apply a different treatment process the selected cavities. We treated some cavities with ElectroPolishing (EP) and one cavity, already integrated in the He-tank, with rotational BCP. The EP process was adapted at the cavity vendor based on their experience from XFEL and LCLS-II projects as well our joint activities done on prototypes in the framework of the PIP-II project [12]. The Rotational BCP on a integrated cavity was done at Argonne National Laboratory in a framework of a joint collaboration.

Cavity M024, limited to 8 MV/m with a significant Q-drop, was the first unjacketed cavity treated with EP [10]. The results were, after the first VT, very encouraging and, in fact, we measured E_{acc} = 17 MV/m. The following inspection done at the vendor before starting the integration showed a cavity geometrical deformation and an Field Flatness of 85 %. The cavity was put back within the requested specifications and integrated into the He-Tank by the vendor. The following VT showed the result presented in Fig. 3, limited by quench at E_{acc} = 13.7 MV/m. The analysis of the performance highlighted that the cell with lower field was also the quenching one: once tuned to proper field flatness, it was the cause of the overall cavity limitation.

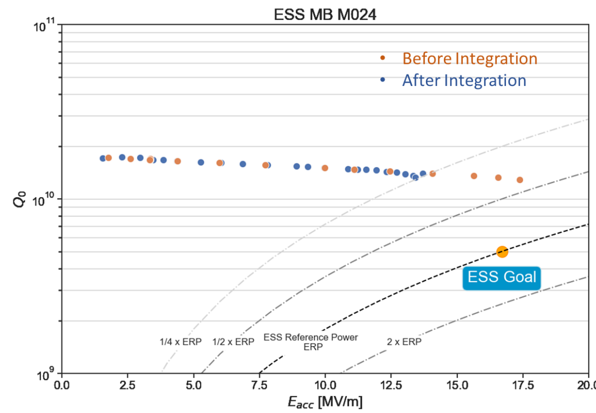

Figure 3: ESS Medium Beta M024 Vertical Test power rises comparison before (orange dots) and after (blue dots) He-Tank integration. To be noticed that before the integration, the Field Flatness was 85 %.

Nevertheless, the EP process recovered fully the significant Q slope at low field showed by the cavity with an improvement of the maximum accelerating gradient of about 80 %, indicating that the dissipating mechanism attributed to the grooves observed on the inner wall of the cell was indeed one of the plausible causes of the cavity low performance. For this reason, we proceeded treating also the other two unjacketed cavities with EP. The results are reported in the following two subsections.

M017 - Unjacketed

Cavity M017 was initially treated with BCP and reached a quench at 7.4 MV/m. The cavity was then processed with 110 µm of bulk EP and prepared for test with additional 10 µm of cold EP. The performance of the cavity is reported in Fig. 4.

As for cavity M024, we notice a significant recovery of the Q slope. The cavity is limited by quench at E_{acc} = 11.5 MV/m, with an improvement of about 55 % of the maximum accelerating gradient.

M037 - Unjacketed

Cavity M037 was initially treated with BCP and reached a quench at E_{acc} = 9.1 MV/m. The cavity was then process with 110 µm of bulk EP and prepared for test with additional 10 µm of cold EP. The performance of the cavity is reported in Fig. 5.

As for cavity M024, we notice a significant recovery of the Q slope. The cavity is limited by quench at E_{acc} = 15.7 MV/m, with an improvement of about 100 % of the maximum accelerating gradient.

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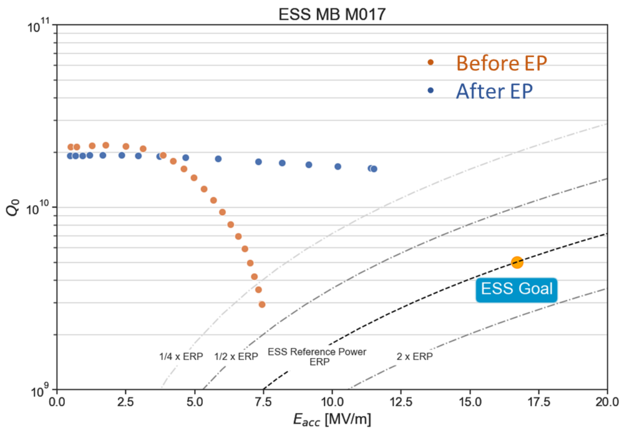

Figure 4: ESS Medium Beta Cavity M017 unjacketed power rise after EP

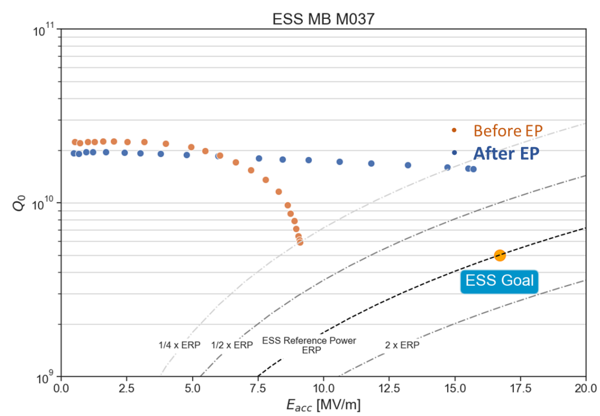

Figure 5: ESS Medium Beta Cavity M037 before and after the EP process. A significant improvement in cavity performance is notable.

NEW CAVITIES PRODUCTION

Four new cavities have been produced to mitigate possible further delays and, possibly, substitute some of the low performance cavities. The mechanical preparation of these cavities has been similar to the series production. Given the experience of BCP treatments, we decided to use EP for the bulk treatment (160 µm) while the last treatment, being the cavity already integrated, is a flash BCP process. Moreover, we introduced an intermediate vertical test of the naked cavities after the main EP and an additional final cold EP (10 µm) before the integration to be able to apply any corrective action it would be necessary.

The four cavities have been all mechanical fabricated and EP treated. Two cavities proceeded naked to the Vertical Test while the other two showed two defects in the equator area that required a grinding operation. Figure 6 reports the power rise of the two cavities before integration.

The cavities clearly outperformed the ESS specifications. These two cavities are now in the integration process and they will be tested by June of this year. The reamining two cavities are instead in preparation for the intermediate VT

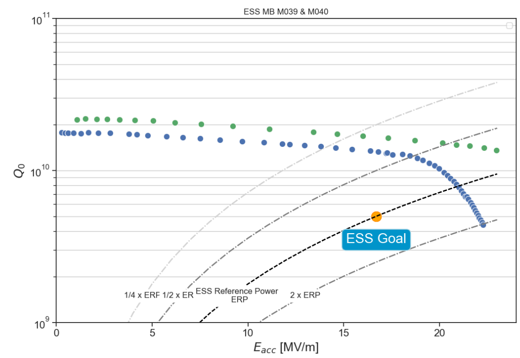

Figure 6: ESS Medium Beta Cavities M039 (blue dots) and M040 (green dots) power rises.

test, this also foreseen in June. After the positive test, these two cavities will also proceed to integration. We estimate to be ready for final test after integration by fall '23 and deliver the whole package by end of 2023.

CONCLUSION

The Italian In-Kind contribution to the Medium Beta Section of the ESS linac is progressing to complete the delivery of the required 36 cavities. Twenty-eighth have been qualified and delivered for installation in the cryomodule. Four new cavities are in production and, the intermediate results, show very good performances. The recovery of the low performance cavities with EP show significant improvements such that these cavities could be possibly used in the first cryomodules of the Medium Beta section where the matching condition from the spoke section are requiring significantly lower accelerating field. The four new cavities, EP treated, show very good performance and motivate a possible further contribution with four spare cavities to ESS, now under discussion.

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