ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOTK027

# FIELD EMISSION MEASUREMENTS AT LUND TEST STAND

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*Abstract*

We present here a description of field emission (FE) measurements set-up developed for elliptical cryomodules test activities at Lund Test Stand 2. A test campaign of field emission measurements has been developed and optimized during cryomodules tests. The scintillator detectors (and their respective shields), chosen for these measurements, have been characterized and optimized. The field emission application has been developed and integrated in the cryomodules tests operator interface. The Initial test results are presented and commented.

## INTRODUCTION

The Test Stand 2 (TS2) at ESS in Lund, Sweden, is dedicated to medium and high beta supeconducting cryomodules (CMs) site acceptance test (SAT). During 2021 the test facility was fully commissioned with one prototype module. Between 2021 and first half of 2022 four medium beta modules of the series were successfully tested. The Field Emission (FE) measurements were set-up during the first CM test in order to develop the methodology to assess onset of field emission during module tests. Only partial data is thus available for this first module, CM01.

The goals of the measurements are:

- to quantify the field emission energy endpoint and to collect the count rate increase vs accelerating gradient, $E_{acc}$, to make an assessment where the field emission starts;
- to compare measurements taken during CMs tests with the results from Vertical Tests (VT)[1];
- to build an overview of FE spatial distribution with the goal of quantifying the emitted radiation with respect to the direction of the beam-line.

## MEASUREMENTS SET-UP

To perform FE measurements, scintillators detectors (NaI(Tl) crystals) were chosen [2]. Two GAMMA-RAD 5 gamma rays spectrometers from Amptek (3 x 3 inches scintillators provided with photomultiplier PMT) were chosen as a single, integrated and portable module. The energy resolution of the detectors is less than 7% on the $^{133}$Cs line at 662 keV.

A dedicated shielding has been designed and realized to be able to detect potential high x-rays count rate (Fig. 1).

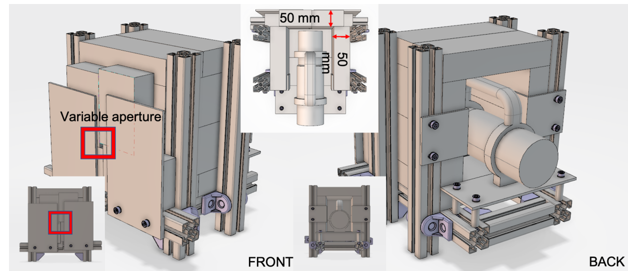


Figure 1: Detectors shielding of varnished bricks and supports. On the left the frontal side is shown; on the right the back side is shown. The thickness is 50 mm thick. The top view is shown in the middle, where the shielding roof has been removed to show detector position.

The lead shielding is 50 mm thick and covers frontally and laterally the detectors. The shielding has a window aperture of 10 x 10 mm. In the measurements presented in this paper the shielding was closed to avoid detector saturation. Dedicated measurements of the detector dead time vs. front aperture will be performed during the testing of the next modules. The two detectors have been calibrated with $^{137}$Cs (661 keV) and $^{60}$Co (1173 and 1332 keV plus the sum peak at 2505 keV) and no additional source above 3 MeV is available. This implies that the measurements at 8 MeV, that is our activation threshold, is evaluated with extrapolation from the calibration with a certain error.

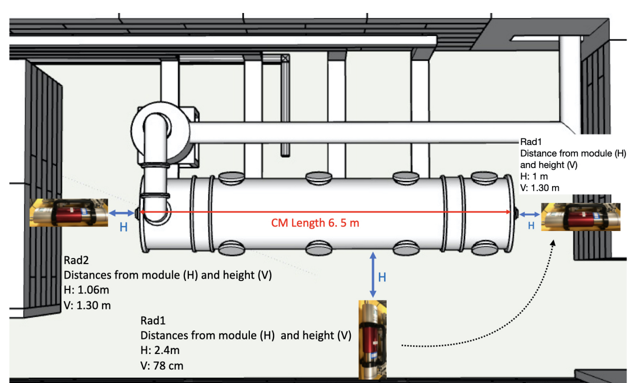


Figure 2: Overview of test stand 2 bunker. The detector 2 was placed along the longitudinal axes of the cryomodule; the detector 1 was used in two configurations: one orthogonal to the symmetry axes of the module and the another on the opposite side with respect to detector 2.

The detectors were placed according to the Fig. 2.

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13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOTK027



# TESTS OF THE FIRST FOUR MODULES OF THE SERIES

For each module tested at Lund Test Stand 2 [3] two kind of field emission measurements are taken for each cavity: energy spectrum and count rate vs. accelerating gradient. We measure also the field emission energy spectrum with the four cavities in the module powered at a gradient $E_{acc}$ of 16.7 MV/m, the nominal ESS pulse length of 3.2 ms and a repetition rate of 14 Hz.

As an example, we present the results of cavity 4 which is hosted in medium beta elliptical module CM04. For this cavity, the VT field emission reported in the INFN dataset starts just above 15 MV/m (Fig. 3).

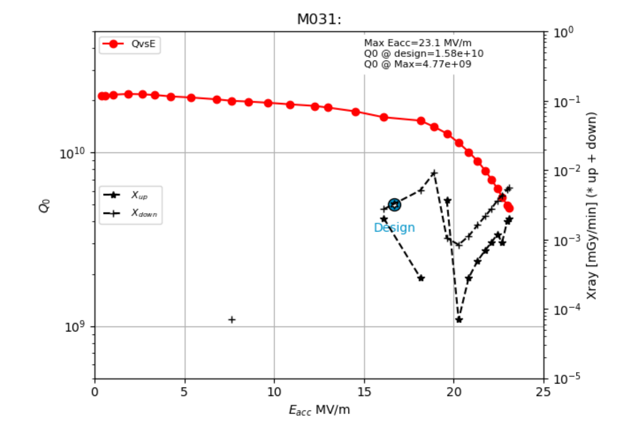


Figure 3: VT result. Field emission starts at 15 MV/m with dose rate that ranges from $10^{-4}$ to $10^{-2}$ mGy/min. Plot generated from the ESS Cavity Database from the VT test data provided by INFN [4].

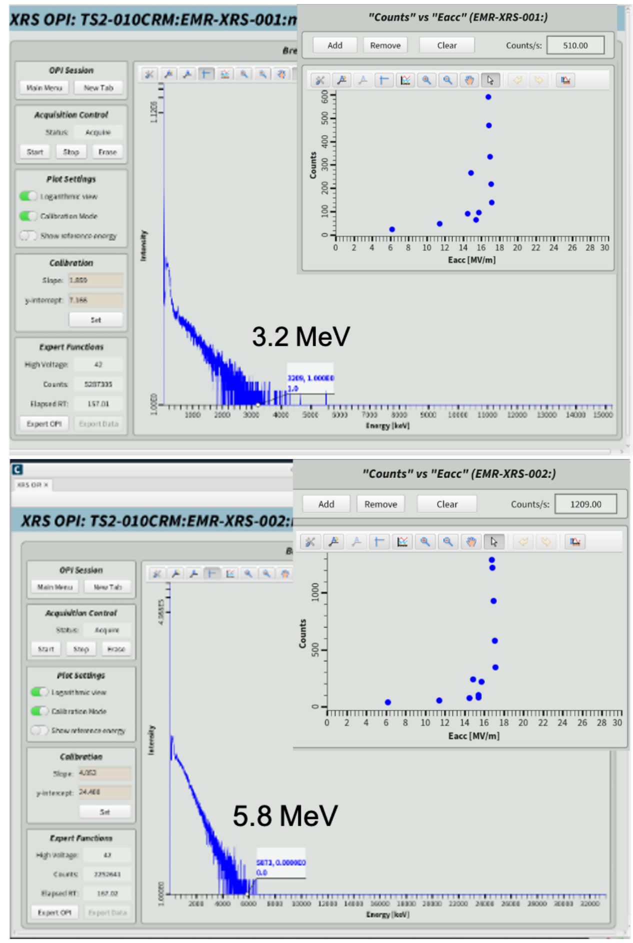


Figure 4: Field emission measured in cavity 4. Top: detector 1. Bottom: detector 2. Both energy spectra and count rate vs $E_{acc}$ are shown.

The CM test was performed with the detector 1 in orthogonal position (see Fig. 2). Both scintillators measured a sharp increase in count rate just above 15 MV/m, but detector 1 measured an energy endpoint of 3.2 MeV, while detector 2, along the beamline, measured 5.8 MeV. The results are shown in Fig. 4 and the count rate vs. $E_{acc}$ is in good agreement with the VT test. The measurement shows that the field emission is not purely along the beamline direction.

Scintillator detectors Operator Interface (OPI) is now fully integrated in cavity conditioning OPI (Fig. 5).

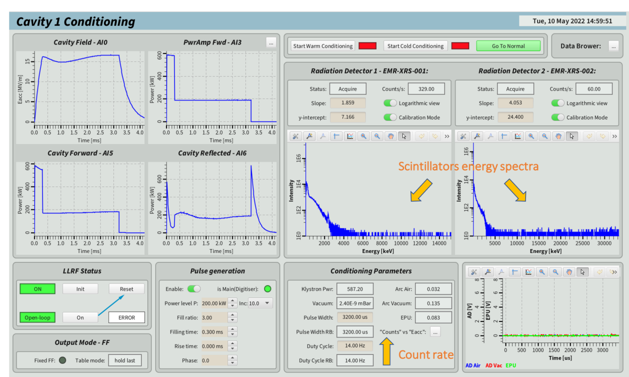


Figure 5: Operator User Interface for cavities conditioning. The detectors energy spectra and count rate are integrated and easily accessible for operators.

# MODULES RESULTS

During 2021 and first half of 2022 four modules of the series have been tested: CM01, CM03, CM04 and CM05 [5]. The agreement between VT and CM field emission onset (in terms of $E_{acc}$) is shown in Table 1 while a more qualitative assessment about the presence of field emission in VT and CM tests is in Table 2.

Among the 16 cavities in the four cryomodules tested, 13 showed a qualitative agreement between VT and CM field emission behavior, two show emission only during CM testing (M020 and M034) and one suffered a problem in the data acquisition (M030). The RF surfaces of the M020 and M034 cavities may have been contaminated between the VT and the CM tests.

A precise comparison of the field emission evolution as function of $E_{acc}$ is more complex to assess. For example, for cavities M014, M025, and M031 the maximum power to the couplers was limited at 300 kW to avoid electrical break-

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Table 1: FE comparison between VT and CM test. For CM04 detector 1 was transverse to the CM, while detector 2 was on the beamline. For CM05 both detectors were on the beamline

| CM | Cavity from 1 to 4 | VT field emission [MV/m] | CM field emission [MV/m] | |
|---|---|---|---|---|
| | | | Detector1 | Detector2 |
| 4 | M014 | From 17 to 19 | From 17 to 18 | From 17 to 18 |
| | M016 | none | none | none |
| | M030 | none | From 15 to 19 | From 15 to 19 |
| | M031 | From 15 to 23 | From 15 to 18 | From 15 to 18 |
| 5 | M023 | From 12 to 18 | From 10.5 to 14.5 | From 12 to 17.5 |
| | M025 | at 19 | From 15 to 17 | From 15 to 17 |
| | M029 | none | none | none |
| | M034 | none | From 15 to 18 | From 15 to 18 |

Table 2: FE comparison between VT and CM test. For CM04 detector 1 was transverse to the CM, while detector 2 was on the beamline. For CM03 and CM05 both detectors were on the beamline

| CM | Cav | FE energy det. 1 [MeV] | FE energy det. 2 [MeV] | FE during VT | FE during CM |
|---|---|---|---|---|---|
| 3 | M007 | 4 | 3 | Y | Y |
| | M018 | 4 | 4 | Y | Y |
| | M020 | 3 | 4 | N | Y |
| | M011 | 5 | 5 | Y | Y |
| 4 | M014 | 4 | 3 | Y | Y |
| | M016 | none | none | N | N |
| | M030 | N/A | N/A | N | N |
| | M031 | 3.2 | 5.8 | Y | Y |
| 5 | M023 | 6 | 6 | Y | Y |
| | M025 | <4 | 6 | Y | Y |
| | M029 | none | none | N | N |
| | M034 | 6 | 6 | N | Y |

down [6]. The range where field emission was observed is shorter in the CM testing with respect to the VT because the cavities were not driven to the same field levels due to this administrative limit. Generally there is an agreement for the onset levels.

## CONCLUSION

Initial results of the field emission measurements on the elliptical medium beta cryomodules have been presented. Field emission energy spectra and count rate during power ramp up has been performed on almost all cavities in CMs tested until now. The comparison between VT and CM showed a rather good consistency, which will be further explored for the remaining module production. The field emission spatial distribution study shows that there is emission in both longitudinal and transversal directions of the cryomodule. These studies will continue during the next elliptical modules at ESS test stand in Lund.

The same technique of X-Rays analysis applied to the evaluation of RFQ voltage was developed at ESS and presented on paper TUPOTK030 [7].

## REFERENCES


[1] A. Bosotti *et al.*, "Vertical Tests of ESS Medium Beta Prototype Cavities at LASA," in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 1015–1018. doi:10.18429/JACoW-IPAC2017-MOPVA063

[2] "Gamma-rad5 gamma ray detection system." (2019), https://www.amptek.com/resources/obsolete-products/gamma-rad5-gamma-ray-detection-system

[3] R. Garoby *et al.*, "The european spallation source design," *Phys. Scripta*, vol. 93, no. 1, p. 014 001, 2018. doi:10.1088/1402-4896/aa9bff

[4] P. Pierini, A. Bosotti, E. Cenni, C. G. Maiano, D. Sertore, and M. Wang, "The ESS Database for Elliptical Cavities," in *Proc. SRF'19*, Dresden, Germany, Jun.-Jul. 2019, pp. 1152–1156. doi:10.18429/JACoW-SRF2019-THP099

[5] C. G. Maiano *et al.*, "ESS Elliptical Cryomodules Tests at Lund Test Stand," Bangkok, Thailand, Jun. 2022, 13, presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper TUPOTK026, this conference.

[6] C. Arcambal *et al.*, "Status of the Power Couplers for the ESS Elliptical Cavity Prototypes," in *Proc. SRF'15*, Whistler, Canada, Sep. 2015, pp. 1309–1312. https://jacow.org/SRF2015/papers/THPB078.pdf

[7] E. Laface, C. G. Maiano, R. Zeng, and O. Piquet, "X-Rays Energy Measurements During the RFQ Conditioning at the European Spallation Source," Bangkok, Thailand, Jun. 2022, 13, presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper TUPOTK030, this conference.