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FIRST RESULTS OF THE SXMAP CAVITY FIELD EMISSION DETECTION SYSTEM FROM INSIDE A CRYOMODULE

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Abstract

Field emission (FE) has been one of the limiting factors in achieving high gradients in superconducting RF cavities. While the causes for FE are mostly known (contaminants on the inner cavity surface, dust, gases adsorbed…), identifying the exact location of field emitters has been a challenge. A detection system developed by Kyoto University has been developed to address this task, the sXmap system. This diagnostic device is made of inexpensive sensor strips that wrap around the iris of a multi cell SRF cavity that sense x-rays generated by FE. In this paper we will present the results obtained from a naked 6 cell SRF cavity in a vertical test configuration, and – for the first time – the results obtained from applying the sensor strips to an SRF cavity already installed inside a cryomodule in our test cave at ORNL – SNS.

INTRODUCTION

Field emission is widely considered one of the limiting factors in achieving high accelerating gradients in superconducting radio frequency cavities. As the demand for more powerful or more compact particle accelerators increases, so does the need to achieve higher gradients, and therefore the need to control and minimize field emission.

State of the art cavities technology nowadays is capable of minimizing field emission to a satisfactory level [1, 2], at least during cavity qualification in vertical tests. During the cavities installation in cryomodules though, the challenge has been preventing the field emission onset from shifting to a gradient below target specification, which reduces the overall total gradient of a LINAC.

After extensive beam operation, the field emission threshold for a cavity may shift due to contamination or degradation, also reducing the overall performance of the cryomodule by interacting with the surrounding cavities.

Since SNS has been operational since the late 2010s, new tools to quantify the degradation of cavity performance will be useful to help us plan for future machine intervention, both to preserve performance and beam availability for the user facilities. One of such tools, the sXmap system, is being deployed to better understand SNS cavity field emission and to validate our internal cavity reprocessing facilities [3, 4].

EXPERIMENTAL

The sXmap system was previously tested at ORNL on a 6 cells unjacketed single cavity. The lack of titanium jacket allowed us to install 7 sXmap strips, one for each iris of the cavity. As shown in [3], the strips were slid under the cavity stiffening rings.

This is of course not possible on a jacketed cavity, since the stiffening rings are inaccessible, limiting our test to the use of just 2 sXmap strips. The strips were positioned at each end of one of the cavities inside a high β SNS spare cryomodule. The specific cavity (cavity B) was chosen due to its history of poor performance and high field emission detected at ~8 MV/m. Figure 1 shows the strips wrapped around the beampipe as reasonably close as possible to the cavity under investigation.

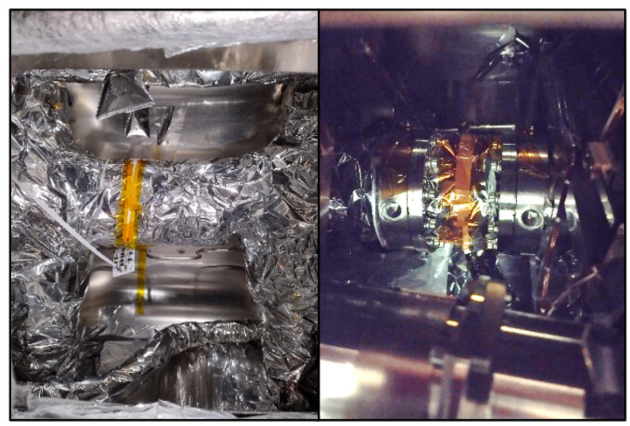

Figure 1: sXmap strips installed on spare cryomodule.

Due to limitations in the SNS cryomodule test cave RF system that doesn't allow to power multiple cavities at once, the cavity was individually energized – which proved beneficial in ruling out potential field emission being generated by other cavities in the cryomodule.

The cavity was tested up to a gradient of 10 MV/m, when the test was stopped due to the field emission reaching administrative limits for our test cave. It is worth noting that the cavity has a design specification of 15.5 MV/m, which it is not able to achieve. While the test was running, the sXmap system was logging data as shown in Fig. 2.

RESULTS

High β Cryomodule Cavity Test Results

Figure 2 shows the data collected by the sXmap system strips during the cavity test at different accelerating gradients. The data related to gradients below 5.5 MV/m are not reported due to the lack of x-ray emission. sX-01 identifies the strip placed downstream of the cavity in respect to the beam direction, while sX-02 identifies the strip upstream.

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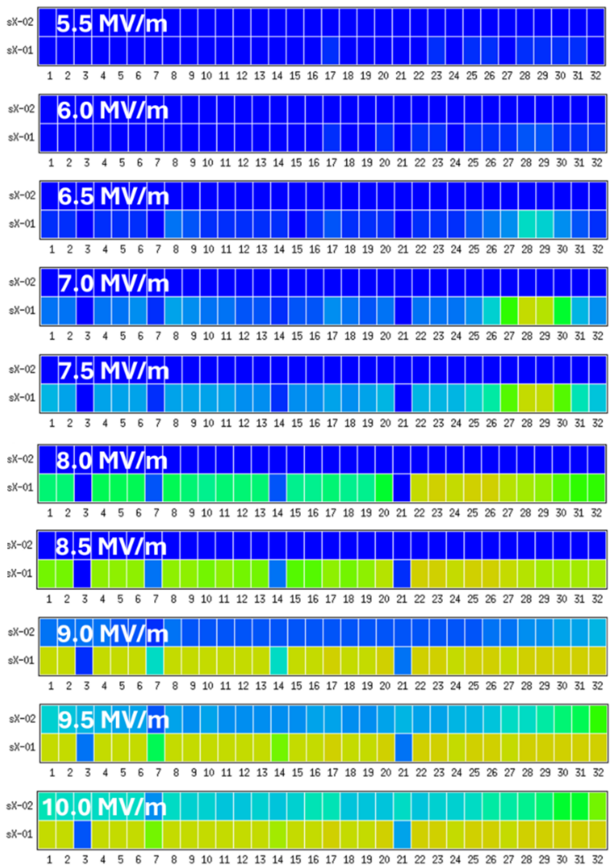

Figure 2: sXmap cryomodule test results.

The great advantage of the sXmap system is that it can be placed much closer to the cavities than traditional radiation monitors, that due to physical constraints must be located outside the cryomodule, reducing their detection sensitivity.

The data show that, for this cavity, the field emission onset is not at 8.0 MV/m, as detected by the radiation monitors, but at 6.0 MV/m. Sensors 28 and 29 start detecting x-rays at 6.0 MV/m, although the signal is weak. At 6.5 MV/m the signal is already quite strong, and as the gradient increases so does the signal, to the point of almost saturating the sXmap strip at 10.0 MV/m. Moreover, it can be noted that at 9.0 MV/m and above the upstream sXmap strip starts detecting x-rays too, that could be coming from the same source that is irradiating the downstream strip.

Further studies are planned to use the result of this test to identify the position of the emitter (or emitters), but only one strip at each end of the cavity may be insufficient to derive any definite positional data.

Visualization Tool

A new tool was developed to help visualizing the evolution of the field emission signal on the sensor strips with the change of the cavity gradient. Figure 3 shows the intensity of the field emission detected at 4 different gradients (7, 8, 9 and 10 MV/M) for the cavity B inside the spare cryomodule tested.

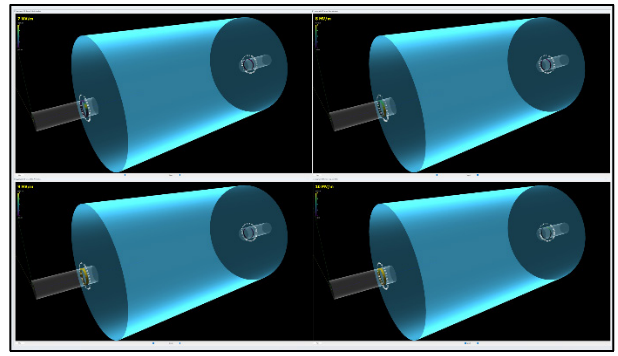

Figure 3: sXmap visualization tool.

LINAC Cryomodule Future Test

Based on the results of the cryomodule cavity test, a plan has been developed to install the sXmap strips inside a production cryomodule inside the SNS LINAC. This will be the first time this system will be used inside a proton accelerator, and it will allow us to verify the robustness of the sXmap strips once exposed to a proton beam.

While the first test inside the spare cryomodule was successful, there was a concern that the Kapton tape used to hold the strips around the beampipe could come loose at cryogenic temperatures, detaching the strips from the beampipe and rendering the test unreliable.

Custom clamps were therefore designed and 3D printed. Figure 4 shows one of the half clamp prototypes. A grooved channel on the inner surface of the clamps allows for the insertion of the sXmap strips, preventing them from moving and allowing us to precisely position them.

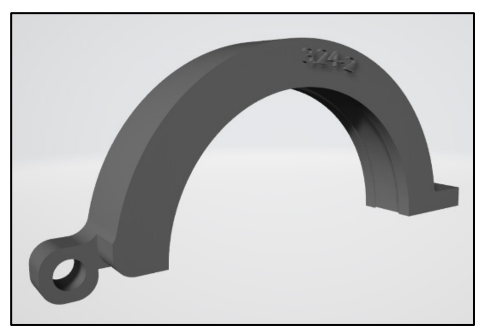

Figure 4: sXmap strip mounting clamp prototype.

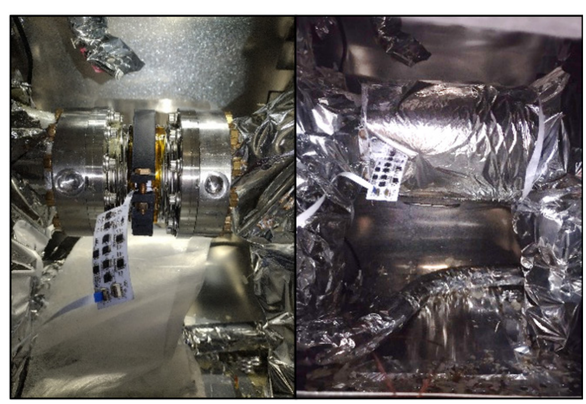

Figure 5: sXmap strips installed on LINAC cryomodule.

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During the most recent maintenance period, two strips were installed inside one of the LINAC cryomodule (position 12, on each end of cavity B), as shown in Fig. 5, that had to be warmed up for maintenance. The plan was to perform the same test during the cavities startup and monitor the system with the beam running. Unfortunately, after the cryomodule was cooled down at the end of the maintenance period, the signal to the sXmap strips was lost. It is difficult to speculate on the cause for the lost signal, but it is most likely due to an electrical short. During the next maintenance period (Nov 2025) we expect to warm up the same cryomodule, which will give us the possibility to troubleshoot the system.

CONCLUSION

The sXmap system was successfully tested on a jacketed SRF cavity inside an SNS style high β cryomodule. The space constraints prevented us from mounting more than two strips, but we successfully gathered data consistent with the studied cavity history. Progress is being made to test the system on a cryomodule inside the LINAC during beam production, to be expected by the end of this year. If successful, this will tell us if the sXmap system can be used as a reliable field emission detection tool not just on a test facility, but on a production LINAC.

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