EFFORTS TO IMPROVE THE ASSEMBLY WORK OF SRF CAVITIES IN THE CLEAN ROOM TO SUPPRESS FIELD EMISSION

Mathieu Omet†, Hayato Araki, Takeshi Dohmae, Hayato Ito, Ryo Katayama,
Hiroshi Sakai, Kensei Umemori, Yasuchika Yamamoto,
High Energy Accelerator Research Organization, Tsukuba, Japan

Abstract

Our main objective is to achieve as high as possible quality factors Q0 and maximal accelerating voltages Eacc within 1.3 GHz superconducting radio frequency (SRF) cavities. Beside an adequate surface treatment, key to achieve good performance is a proper assembly in the clean room prior cavity testing or operation. In this contribution we present the methods and results of our efforts to get a better understanding of our clean room environment and the particulate generation caused during the assembly work. Furthermore, we present the introduced measures of documentation to support the planning, the performance, and the analysis of the assembly work.

INTRODUCTION

Superconducting radio frequency (SRF) cavities [1] are a state-of -the-art technology applied in many accelerators around the world. The key performance parameters are the unloaded quality factor Q0 and the accelerator voltage Eacc. Both parameters can be degraded by field emission (FE) [2]. Beside surface defects, particulate contaminations can be strong field emitters. Thus, the pollution of the inner cavity surface with particulates must be avoided. The two sources of particulates are the environment (e.g. particulates in the clean room) and their generation during the assembly process. In the first case it is important to understand the cleanliness of the environment so that improvements can be implemented. In the second case the particulate generation mechanisms and the particulate movements must be understood. In this proceeding we report on the effort taken addressing these points. In addition, we report on further measures taken to suppress FE as well as FE statistics of the five and a half years.

CAVITY PREPARATION AND TEST CYCLE

After a new cavity was produced or received, the first step is to perform an optical inspection of the inner surface using the Kyoto camera [3]. After cleaning the cavity, it is annealed e.g. at 900 °C for 3 hours. This is followed by a 100 µm bulk electro polishing (EP) EP1 [4] and high-pressure rinsing (HPR) with ultra-pure water.

A typical cavity preparation and test cycle is as follows. The cavity is optically inspected using the Kyoto camera. If defects are found, they are locally grinded. After this the cavity is moved the tuning machine. On it the frequency and field flatness are tuned. Furthermore, the cavity is straightened, if necessary. In the next step, EP2 and HPR is applied. The cavity is moved directly from the HPR stand into the clean room, where it is assembled. Afterwards the cavity is connected to a pumping station and leak checked. Is this passed, the cavity baked e.g. at 120 °C for 48 hours [5]. In the last lest the cavity is moved to the vertical test (VT) stand and tested at 4 K and 2 K.

CLEAN ROOM SURVEY

A common method to evaluate the cleanliness of a clean room is to setup a particle counter at different locations and heights and record the particle counts for certrain periods of time. In the studies presented below we took a new aproach utelizing different light sources, allowing the inspection of surfaces. In preparation of the studies described in the following, the ambient lights inside the clean room were turned off. Since most of the clean room walls have huge windows in them, there was still a certain level of ambient light present.

Normal Light

For the study a strong spotlight was chosen. It was directed on different surfaces inside the class 1000 clean room. The inspection of the surface was done visually. For documentation purposes pictures were taken. On most walls slight dust could be seen. The walls and windows close to the entrance door showed significant contamination. In this area a hand-wash basin and an ultra-sonic bath is located. Also, the walls and windows in front of the high-pressure rinsing (HPR) stand showed significant contamination (see Fig. 1). In this area the outer surface of the cavities is manually dry blown after HPR. On a table beside the pumping stand dust and fibres could be seen. In this area the cavities are being baked using heater ribbons and a heater jacket.

Figure 1: Window of air shower between STF class 1000 and class 10 clean room.

† mathieu.omet@kek.jp

D Light

In a further study we evaluated the usability of another light source: the ViEST D Light Type F provided by Sin Nippon Air Technologies (SNK) [6]. The spectrum of this light source is distributed around violet, reaching also into the ultraviolet region. It allows the observation of contaminants and stains with fluorescent components. It is used in combination with dedicated set of googles for diffuse reflection suppression.

In a first test a with dust contaminated surface was observed with a stationary camera. Pictures were taken for different positions and angles of the light source. The visibility of the dust was very similar for all light positions.

In a second test another contaminated surface was observed. Many bright dots were seen, which were interpreted to be dust. The surface was clean blown, wiped with alcohol, and clean blown again. After this only very few bright dots remained. This was interpreted as a confirmation that we indeed can observe dust using the D light.

In the following 564 different surfaces in the following areas were investigated: COI changing room, COI class 1000 clean room, COI class 10 clean room, STF changing room, STF class 1000 clean room, and STF class 10 clean room.

In the changing rooms at both facilities a lot of dust and stains were found. Also, the walls of both air locks with air showers were dusty. Furthermore, on most of the surfaces in all clean rooms dust particulates were visible. Prominent places were tools and tool trays. Beside this, on surfaces of in shelfs stored items and on surfaces of devices such as pumping stations and ultra-sonic baths, dust particulates were present.

From this study it was concluded that cleaning of certain surfaces was necessary. After cleaning (alcohol wiping and clean blowing) of e.g. windows within the STF class 1000 clean room, no dust particles were visible (see Fig. 2).

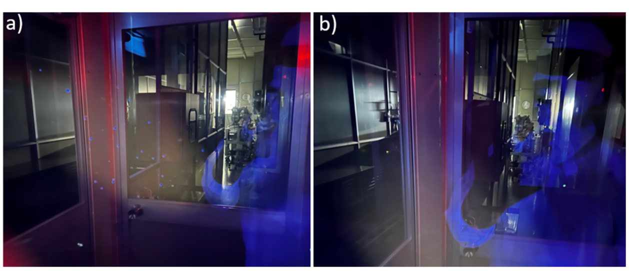

Figure 2: Window of air shower between STF class 1000 and class 10 clean room: a) before cleaning, b) after cleaning.

It was not feasible to clean the entire clean rooms with all items in them. Thus, it has to be avoided to whirl up dust from e.g. behind shelfs or torque wrenches, etc. Furthermore, in the clean room stored items need to be cleaned before usage.

STUDY ON PARTICLE GENERATION DURING ASSEMBLY

The goal of this study was to learn about the particulate generation, distribution, and dynamics during an assembly procedure of a 9-cell TESLA-type cavity. It was conducted togther with employees from SNK. A green laser emmitter was placed in the STF class 10 clean room [7]. The laser beam as fanned out and transmitted through an area of interest. Particulates falling or floating through the laser beam scattered the light. This is recorded by a narrow-band video camera. In order to allow the laster operation, all windows of the surrounding class 1000 clean room were shaded. This measure improved at the same the signal to background/noise ratio.

The in the following descibed tests are only a selection of a larger number of tests performed.

In one configuration the faned out laser beam was passed by just in front and below the input coupler port. The port was closed with a bling flange and an O ring. During the recoding the flange, the port, and the surrounding are were clean-blown with an ion gun. At the same time also a hand-held particle counter was used. It showed in total less than 10 particles. On the video the scattered light of many particulates were seen (see Fig. 3 for a single frame). Most particulates move quite fast and have a downwards trajectory.

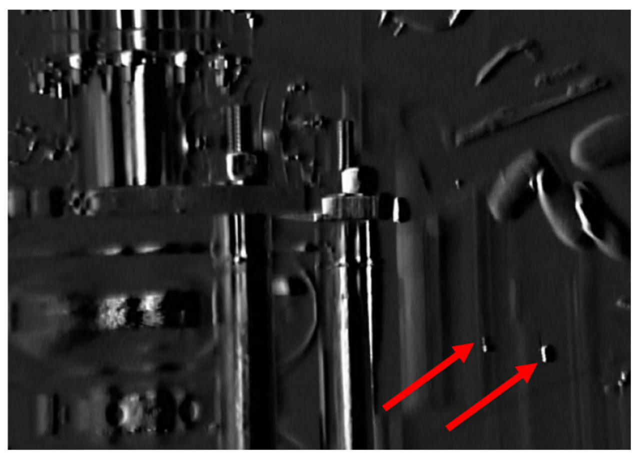

Figure 3: Scattered light of particulates passing through fanned out laser beam.

In the next step the blots holding the blind flange were released. During this work the scattered light of many slowly moving particulates were recorded. Most of them were floating with both upwards and downwards movements.

After removing the blind flange a L-shaped vacuum pipe connected to a vacuum valve was assembled to the coupler input port. The video recorded during the tightening of the bolts showed that many particulates were produced and released. These were floating in the air with a mostly downward direction. But also particulates floating upwards were observed.

From this study we could conclude that the hand-held particle counter only gives a rough idea of how many particulates are actually present in the working area. Its small inlet nozzel is not capable of sucking in enough air to measure particulates in a larger volume. We furthermore could confirm that it is imperative to clean the working area properly. Also slow and careful movements can avoid the release of particulates from the clean wear surface.

ASSEMBLY WORK PLANNING, DOCUMENTATION AND ANALYSIS

Ensuring a consistently high assembly quality is essential not only in cavity mass production, but also during the cavity R&D process. To this end we follow the steps described in the following.

Work Planning

Typically, a week before the assembly process, a work plan detailing the procedure is written. It is then discussed within the workgroup and afterwards with the supporting technical staff. The work plan is uploaded to the cavity's electronical logbook, so that everyone always has access to it. This way the work plan is also accessible via a tablet PC in the STF class 1000 clean room. In case of uncertainty during the assembly it is always possible to check on the previously decided plan.

Video Recording

In case of a special or unique assembly processes, videos of the assembly are recorded. These are taken by either a camera placed in the class 1000 clean room pointing through a window into the class 10 clean room or by a head-mounted camera. The recorded videos are stored and shared by a group-internal cloud storage. This way every group member can review the entire assembly process. Typically, an edited version of the video, showing only the essential assembly steps, is shown and discussed during a group meeting. Especially the videos from the head-mounted camera are very valuable, since they show the most detail.

Analysis of Assembly Work

After the assembly process very divergence of the original work plan is noted down. All recorded pictures and videos are reviewed. Using all available materials, a work report is compiled, typically in form of a PowerPoint presentation. This report is then presented and discussed within the weekly group meeting. Based on this, improvements for future assemblies are decided. All reports are accessible on an internal meeting webpage.

FURTHER MEASURES TO REDUCE FIELD EMISSION

Beside the optimization of the assembly process, we have also introduced further measures to reduce field emission.

Typically, grinding on all irises of the cavity to be assembled and tested is performed. The goal is to remove all surface defects. This is followed by an EP2. Only in rare cases new surface defects are seen after the EP.

As a further measure to reduce field emission, the ion gun in the STF class 10 clean room was replaced. Before the Simco Top Gun was used. Now the Keyence SJ-L005G is used.

Beside this the scroll pumps at the pumping station in the STF class 1000 clean room and at the STF vertical test stand have been replaced with dry pumps.

FIELD EMISSION STATISTICS

Improving the assembly method, required tools and devices is a continuous and lengthy process. To check the overall effectiveness of our efforts, cavity vertical test data from January 2017 to August 2022 was evaluated. The key parameters checked were the gradient, on which field emission occurred (onset), and the maximal acceleration gradient possible. In both cases only data for the final π-mode measurement at 2 K were included. Three different types of cavities have been tested, namely single cell, 3-cell, and 9-cell cavities. Since all three types pose different kind of challenges, simply due to their different geometries, they were evaluated separately.

Single-cell Cavities

The number of single-cell vertical cavity tests evaluated is 112 (see Fig. 4). 75 tests (67.0%) did not show any field emission. For the remaining 37 tests (33.0%) the average onset gradient is 27.3 MV/m. The spread of both, onset gradient and maximal acceleration gradient is quite large. In both no real trend can be seen.

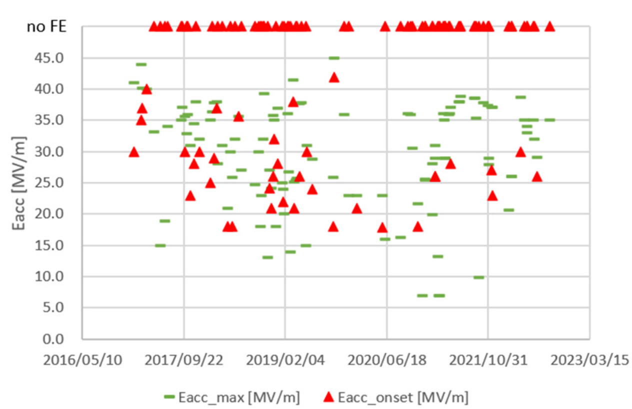

Figure 4: Maximum accelerating gradient (green bars) and onset gradient (red triangles) over time for VTs of single cell cavities.

3-cell Cavities

The number of single-cell vertical cavity tests evaluated is 14 (see Fig. 5). 7 tests (50.0%) did not show any field emission. For the remaining 7 tests (50.0%) the average onset gradient is 22.7 MV/m. Both, for the onset gradient and the maximal acceleration gradient a clear positive trend can be seen.

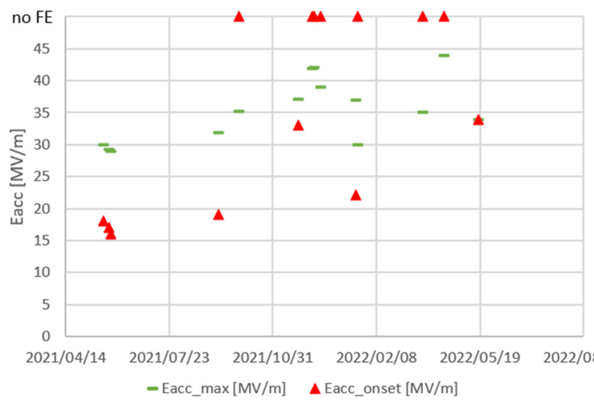

Figure 5: Maximum accelerating gradient (green bars) and onset gradient (red triangles) over time for VTs of 3-cell cavities.

9-cell Cavities

The number of single-cell vertical cavity tests evaluated is 52 (see Fig. 6). 11 tests (21.2%) did not show any field emission. For the remaining 41 tests (78.9%) the average onset gradient is 28.8 MV/m. Although the spread is quite large, for both, for the onset gradient and the maximal acceleration gradient, a positive trend can be seen from May 2019 until January 2022. From February 2022 the trend was not followed. The reason is most likely the new cavity R&D performed in that period.

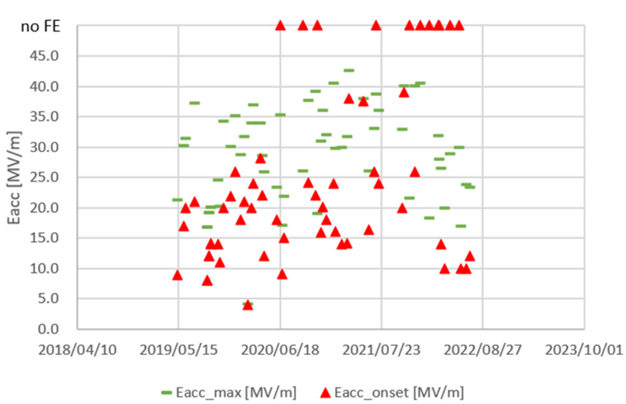

Figure 6: Maximum accelerating gradient (green bars) and onset gradient (red triangles) over time for VTs of 3-cell cavities.

Comparison

With the number of cells per cavity, the number of vertical tests showing field emission is increasing (see Fig. 7 a)). At the same time the average onset gradient as well as the ratio of the onset gradient and the maximum accelerating gradient decrease with the number of cells per cavity (see Fig. 7 b) & c)). The reason for this is most likely the increased inner surface area as well as the complexity of the cavity shape. E.g. single-cell cavities have less ports (only 2) compared to 9-cell cavities (6 ports plus complicated structures such as the higher order mode (HOM) pickups).

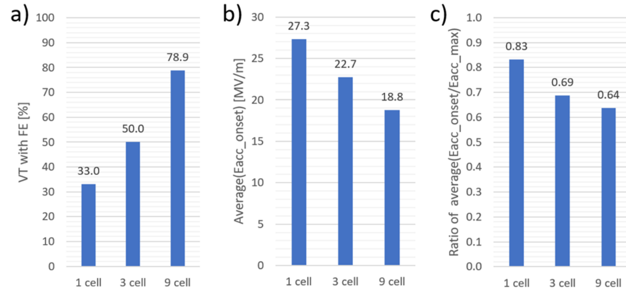

Figure 7: Comparison of single cell, 3-cell, and 9-cell cavity tests: a) percent of tests showing FE, b) average onset gradient, c) radio between onset gradient and maximal accelerating gradient.

CONCLUSION

The suppression of field emission in SRF cavities is a complex undertaking. The two key aspects are to remove surface defects and to avoid contamination of the inner surface. For the first aspect an appropriate approach is iris grinding followed by EP. The latter aspect is influenced by many factors, e.g. the cleanliness of the environment, the particulate production when using tools, the particulate production within devices, and the assembly quality. We are continuously evaluating and improving our procedures and tooling to avoid or mitigate possible surface contamination.

ACKNOWLEDGEMENTS

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