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RECENT ACTIVITIES REGARDING 9–CELL TESLA–TYPE CAVITIES AT KEK

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Abstract

In this contribution we report on two topics regarding recent activities on 9–cell TESLA–type cavities at the High Energy Accelerator Research Organization (KEK). First, we give an overview of the inner surface treatments and vertical test (VT) results of four fine grain 9–cell TESLA–type cavities over the last one and a half years. Secondly, we report on the upgrade of the VT DAQ system at the Superconducting RF Test Facility (STF) at KEK. In this upgrade, most components of the VT system were integrated in an EPICS control system. Based on Control System Studio (CSS) and Python a new user interface was created, improving the workflow during and after VTs at STF.

INTRODUCTION

In preparation of the possible realization of the International Linear Collider [1], the High Energy Accelerator Research Organization (KEK) is conducting R&D for the cost reduction of superconducting 9–cell TESLA–type 1.3 GHz cavities. To this end, new treatment methods are applied to four cavities. They are named MT–3, MT–4, MT–5, and MT–6 and are depicted in Fig. 1. All four cavities have a RRR > 300 and are manufactured from fine grain Niobium by Mitsubishi Heavy Industries Machinery Systems.

Figure 1: Top left: MT–3, top right: MT–4, bottom left: MT–5, bottom right: MT-6.

TESLA-TYPE CAVITY TESTING

R&D Cycle Overview

The cavity R&D cycle typically consists of a treatment and preparation phase, which is followed by a testing and evaluation phase. All procedures are performed at the Superconducting RF Test Facility (STF) [2] and the Center Of Innovation (COI) [3] on the KEK campus. At COI a furnace is located, which is used for the annealing process. At STF, electro-polishing (EP) procedures can be applied [4]. This is always followed by a high pressure rinsing (HPR) of the cavity. The next step is the assembly of the cavity, which can be done in a clean room at either facility. Baking is typically performed using a heater jacket inside the clean room. In a next step, the cavity performance is measured. This is done by a vertical test at cryogenic temperatures with radio frequency (RF) applied to the cavity. After the evaluation of the cavity performance and the limitations, actions for the following R&D cycle are decided. Table 1 gives an overview of the treatments applied as well as the VT results.

Table 1: Treatments and VT Results (Highest Recorded Gradient During the Final π–Mode Measurement) of MT-3 to MT-6 as of June 2021

MT-3	MT-4	MT-5	MT-6
100 µm EP1 900 °C 3 h 20 µm EP2 120 °C 48 h **VT1 16.3 MV/m**	100 µm EP1 900 °C 3 h 30 µm EP2 120 °C 48 h **VT1 cold leak**	100 µm EP1 900 °C 3 h 20 µm EP2 120 °C 48 h **VT1 35.1 MV/m**	100 µm EP1 900 °C 3 h 30 µm EP2 120 °C 48 h **VT1 28.7 MV/m**
HPR 120 °C 48 h **VT2 cold leak**	HPR **VT2 4.1 MV/m**	20 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT2 34.0 MV/m**	30 µm EP2 120 °C 48 h **VT2 26.0 MV/m**
HPR 120 °C 48 h **VT3 30.3 MV/m**	100 µm EP1 800 °C 3 h 30 µm EP2 120 °C 48 h **VT3 37.7 MV/m, cold leak**	5 µm cold EP2 N–dope (2/0) 5 µm cold EP2 **VT3 22.0 MV/m**	20 µm cold EP2 120 °C 48 h **VT3 23.4 MV/m**
20 µm EP2 120 °C 48 h **VT4 36.9 MV/m**	HPR **VT4 39.2 MV/m**	5 µm cold EP2 **VT4 26.3 MV/m**	30 µm EP2 120 °C 48 h **VT4 31.0 MV/m**
10 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT5 35.4 MV/m**	5 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT5 36.0 MV/m**	100 µm EP1 900 °C 3 h 10 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT5 30.9 MV/m**	Iris wiping 30 µm EP2 120 °C 48 h **VT5 42.8 MV/m**
	HPR **VT6 31.3 MV/m**	20 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT6 40.5 MV/m**	10 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT6 38.0 MV/m**
	Local grinding of iris 2-3 10 µm cold EP2 **VT7 31.7 MV/m**		
	9 µm cold EP2 & 10 µm cold EP2 75 °C 4 h & 120 °C 48 h **VT8 cold leak**		

Reference Measurements

The first goal while going through the cavity R&D cycles is to perform a reference measurement. To this all results yield with two–step baking or N–doping treatment methods are compared. To this end, 100 µm of the cavity surface is removed by EP-1, followed by annealing the cavity at e.g.

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900 °C for 3 hours. Then a standard recipe is applied, which includes the additional surface removal of 20 µm to 30 µm by EP-2 as well as baking the cavity after the assembly process at 120 °C for 48 hours. The final reference measurements of the cavities were established as follows:

- MT–3, VT4, 36.9 MV/m
- MT–4, VT4, 39.2 MV/m
- MT–5, VT1, 35.1 MV/m
- MT–6, VT5, 42.8 MV/m

The gradient mentioned is the highest recorded gradient during the final π-mode measurement. Figure 2 shows the Q_0 and X-ray vs Eacc plots for these VTs.

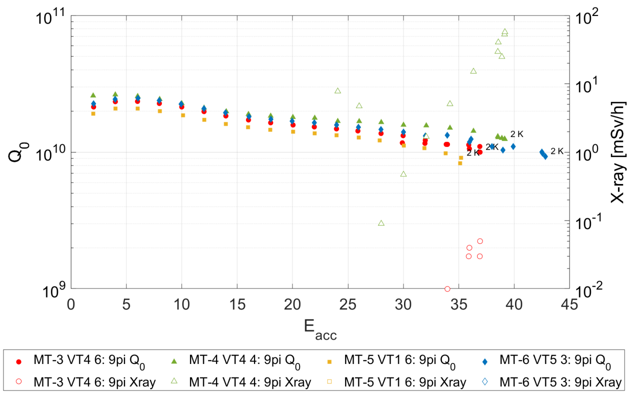

Figure 2: Reference measurement results for MT-3 (red), MT-4 (green), MT-5 (orange), and MT-6 (blue).

MT–3, MT–4, and MT–6 showed Q0 values of over 1E10 at a gradient of 35 MV/m. The radiation onset for MT-4 is at 28 MV/m and for MT–3 at 34 MV/m. It is outstanding, that for MT–5 and MT–6 no radiation was measured, even when reaching up to 42.8 MV/m in case of MT–6.

Special Treatments

Special treatment methods chosen in this R&D campaign so far are two–step baking [5] and N–doping [6]. The procedures applied and the test results are detailed in [7].

Exeptional Cases

In a few cases non-conformities occurred during the preparation or during the testing phase.

During the preparation of VT2 of MT–4, when pumping the cavity after the assembly, the fuse of the pump blew. This led to particulates being sucked from the pumping system into cavity. When RF was applied during the VT, these particulates exploded and caused defects on the cavity surface. Figure 3 shows on the left–hand side pictures of all defects found as well as their positions on the cavity surface on the right–hand side. Only cell 1 did not show any defects. These defects degraded the cavity performance drastically. The highest recorded gradient during the final π-mode measurement was only 4.1 MV/m. As a next step, 100 µm of the surface was removed by a EP–1. The the cavity was annealed at 800 °C for 3 hours. In preparation of the next VT, an additional 30 µm surface removal by EP–2 was applied. The highest recorded gradient during the final π-mode measurement of VT3 was 37.7 MV/m. Thus it was proven, that the previously degraded surface was recovered completely.

Cold leaks during VT2 of MT–3 and VT–1 and VT8 of MT–4 occurred. The first two were due to an issue with the vacuum piping of the VT stand. In order to overcome this issue, the entire vacuum piping of the VT stand was disassembled, thoroughly cleaned, and reassembled. Afterwards no further issues occurred. The cold leak during VT8 of MT–4 occurred at the bottom HOM flange of the cavity. It was verified that the blind flange was assembled adequately. It is assumed that the leak was caused by a problem with the used Aluminum gasket or with the contact surfaces of the HOM port or the blind flange to the gasket. As a reaction to this, these surfaces were polished.

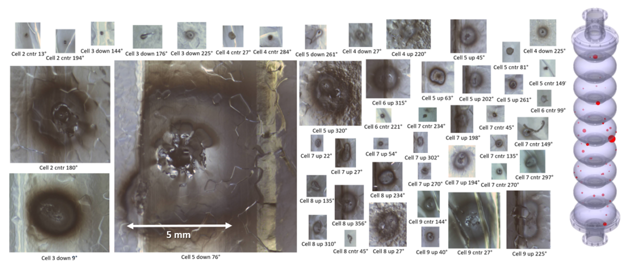

Figure 3: Left: defects on MT-4 inner surface after performing VT2 (all pictures are at the same scale), right: locations of the defects.

UPGRADE OF THE VT DAQ SYSTEM AT STF

The VT pit at STF is used to measure the cavity performance of a large variety of SRF cavities on a weekly basis. Since it was built and commissioned over two decades ago, it consists largely of analog components. In order to modernize the VT system, the following upgrade was implemented in the summer of 2020:

- Two Linux PCs were setup at the VT control room and connected to the local area network (LAN)
- All devices required for a VT were included in the EPICS control system [8]
- A new CSS [9] front-end was established

Figure 4 shows the schematic of how hard- and software components were setup. Server 2 aggregates the data of all the sensors of the VT system and makes them available via the LAN as EPICS records. During VTs, selected records as e.g., power levels, temperatures, radiation levels, etc. are stored in a data archive on Server 3. These and further EPICS records are also monitored and recorded using the newly implemented CSS-based user interface on the Linux PC in the control room of the VT system.

For implementing certain functionalities, shell and Python 3 [10] scripts are invoked in the background. E.g., during the measurement of the standard data as shown in Fig. 5, the decaying RF signal is measured with an oscilloscope. By the push of one button, the data is transferred to the Linux

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PC and via a fitting algorithm, the decay time is evaluated. All cavity parameters are updated and displayed accordingly.

The new CSS-based GUI is deeply integrated with further services, such as the electronic logbook and a cloud storage solution, which are hosted on Server 1. The recording of data such as the standard data or the Q_0 & X-ray vs Eacc data, which is shown in Fig. 6, is realized by writing to local files. These files are stored in a folder, which is automatically synchronized with the cloud storage server. This allows users connected to the LAN, to access the data during or after the VT with ease.

All CSS panels can be documented with a click of a button in the electronic logbook. In this process a shell script in invoked, which takes a screen shot of the corresponding window, creates a new logbook entry with the according metadata (title, author, type, etc.), attaches the screen shot, and saves the logbook entry.

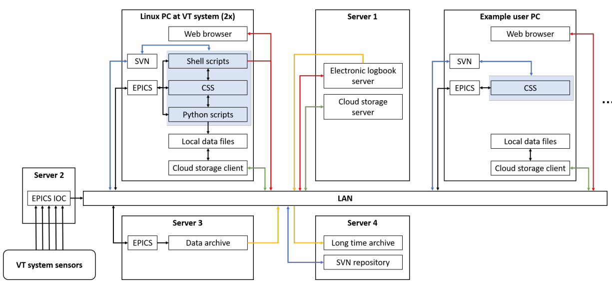

Figure 4: Schematic of the data flow at the STF VT system after the introduction of EPICS and CSS.

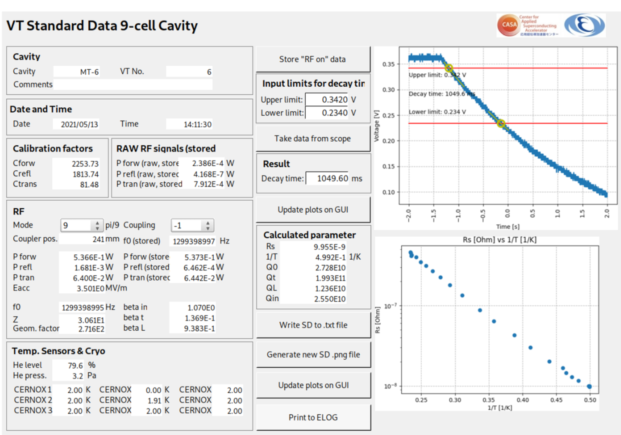

Figure 5: CSS panel for taking standard data.

CONCLUSION

Since 2018 an R&D campaign with the goal of cost reduction of 9–cell TESLA–type cavities is on–going at KEK. To this end four cavities are being treated and tested. So far 25 R&D cycles were performed. Outstanding results for reference measurements (42.8 MV/m) and special treatments (e.g. 40.5 MV/m after two-step baking) were achieved.

With the upgrade of the STF VT DAQ system, the workflow during and after VTs was largely improved. The newly

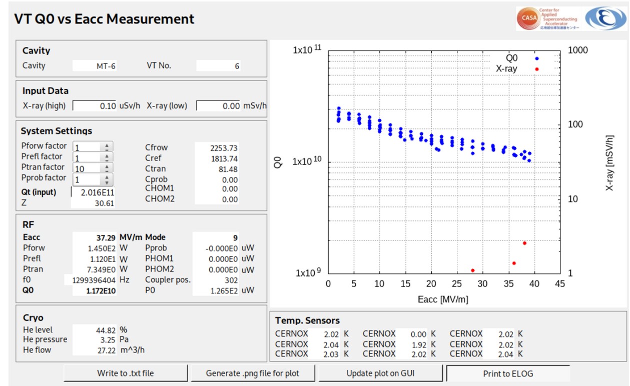

Figure 6: CSS panel for recording Q_0 & X-ray vs Eacc data.

implemented CSS panels were designed in a clear and structured way, reducing the possibility of human mistakes. Data is now visualized in intuitive ways, improving the situational awareness. Every step is recorded in the electronic logbook, allowing an easy review of any VT. The access to the recorded data is simple, allowing a smooth further evaluation.

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