ACHIEVEMENT OF STABLE PULSED OPERATION AT 31 MV/M IN THE STF-2 CRYOMODULE FOR THE ILC

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Abstract

In the Superconducting RF Test Facility (STF) in KEK, the cool-down test for the STF-2 cryomdoules with twelve cavities has been done three times since 2014. In 2016, the third cool-down test was successfully done including the capture cryomodule with two cavities, used for Quantum Beam Project in 2012. In this paper, the result of the third cool-down test is presented in detail.

INTRODUCTION

The STF-2 cryomodule is the one and half size cryomodule, defined "Type B" in Technical Design Report (TDR) for International Linear Collider (ILC) [1], with twelve 9-cell STF-type cavities, called CM1 and CM2a, respectively. In the center of CM1, there are one superconducting quadrupole magnet developed by the collaboration between KEK and FNAL [2], and one beam position monitor developed in Accelerator Test Facility (ATF) [3].

The table 1 shows the history of STF-2 project. In 2014, the first cool-down test was done for the low power measurement by network analyser [4]. In 2015, the second cool-down test was done for the performance check in the single cavity operation [5]. The main purpose in the third cool-down test, which was done in 2016, is to do the vector-sum operation with eight cavities, including the feedforward system, at the average accelerating gradient of 31.5 MV/m as the ILC specification. The others are the measurement for Lorentz Force Detuning (LFD), the heat load measurement, and the Low Level RF (LLRF) study [6], and so on.

Table 1: History of the STF-2 Project

Date	Content
Oct/2013~Jan/2014	Module assembly
Oct/2014~Dec/2014	1st cool-down test
Oct/2015~Dec/2015	2nd cool-down test
Sep/2015~Nov/2016	3rd cool-down test

CAVITY PERFORMANCE AND RADIATION LEVEL

After the cool-down, the achievable accelerating gradient for each cavity was checked again with the radiation level. Regardless of the comparable radiation level as the 2nd cool-down test, many cavities had the performance degradation again. Moreover, two cavities in the capture cryomodule also had the degradation, although they have been kept under vacuum since 2013. The top figure in Figure 1 shows the summary of the achievable accelerating gradient for every cavity in the capture and STF-2 cryomodules. Cav#5, #6, #7, and #9 in the STF-2 cryomodules were not tested in the 3rd cool-down test. The bottom figure in Figure 1 shows the correlation plot of achievable accelerating gradient for ten cavities measured in the 2nd and 3rd cool-down tests. It is clear that almost every cavity had degradation again in the 3rd cool-down test. The causes for the "more" degraded cavities are the followings:

- Change of RF system from single to multi cavity
- Not-optimized forward power to power couplers
- Earthquake (not considered at present)

The change of RF system means that klystron, modulator, waveguide, circulator, and LLRF changed from the single cavity to multi cavity operation. As for the second item, during the vector-sum operation, it is necessary to keep the optimum forward power to each power coupler; however, actually, too-much forward power has been used.

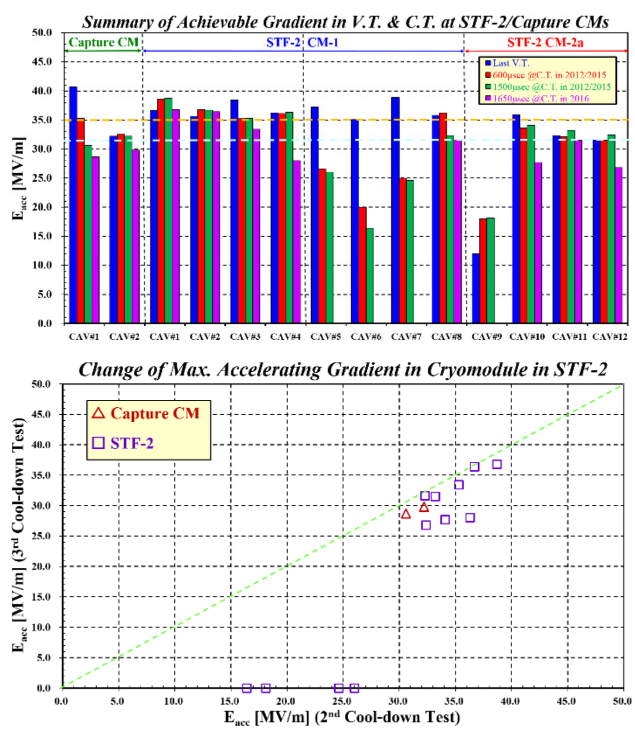

Figure 1: Summary of achievable accelerating gradient for every cavity in the capture and STF-2 cryomodules (top), and the correlation plot of achievable accelerating gradient between 2nd and 3rd cool-down test (bottom). Four cavities on the horizontal axis were not measured in the 3rd cool-down test.

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During the high power test for the STF-2 cryomodule, the emitted x-rays are measured at upstream/downstream beamlines and below the each measuring cavity. The top figure in Figure 2 shows the onset gradient measured in the last vertical test (V.T.), 2nd and 3rd cool-down tests. In the 3rd cool-down test, the onset gradient is comparable or rather higher than 2nd test. The center and bottom figures show the comparison of the radiation level in the last V.T. and two cryomodule tests. There is little difference in the radiation level between two cool-down tests. From these results, it is clear that the field emission is not related to the "more" performance degradation in this test.

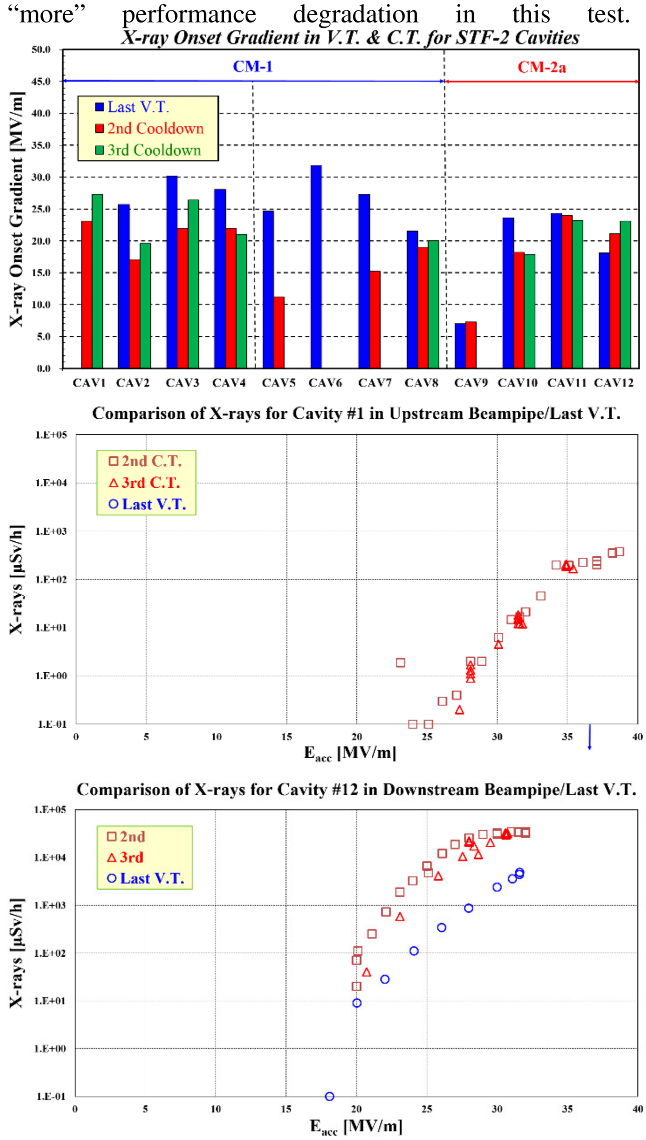

Figure 2: Comparison of x-ray onset gradient in the STF-2 cavities (top), and radiation level for Cavity #1 (center), and Cavity #12 (bottom).

HEAT LOAD MEASUREMENT

The static/dynamic heat load was estimated from the helium mass flow, measured at the downstream of helium gas return line. At this time, in the measurement of static heat load for the STF-2 cryomdoule, the capture cryomodule and quadrupole magnet are also included. The dynamic heat load was estimated by the single cavity operation; the waveguide system is connected to one cavity, and no other connected cavities. Figure 3 shows the comparison of Q-slope and radiation level between the vertical and cryomdoule tests for Cavity #1 and Cavity #4. The systematic error for the unloaded Q in the cryomodule test was estimated from the reproducibility of static heat load, and the root mean square of helium mass flow. The reproducibility of static heat load is consistent within 0.36 W, and the root mean square of helium mass flow is 3.9%. The RF duty is estimated to be 0.85%. The unloaded Q for every cavity in the cryomodule test was uniformly lowered than the vertical test, not related to the radiation level. This situation is same as already described in the previous section. Recently, in FNAL, it was clear that the cool-down rate of cryomodule generates to the change of unloaded Q [7]. Then, in the 4th cool-down test for the STF-2 cryomodule, the cool-down rate will be faster for the higher unloaded Q.

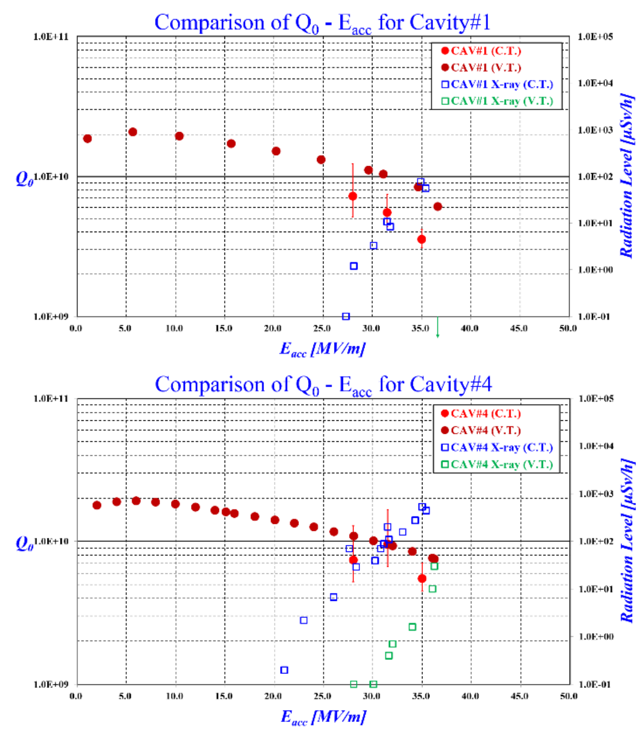

Figure 3: Comparison of Q-slope and radiation level between last V.T. and 3rd cool-down test for Cavity #1 (no radiation in last V.T.) and Cavity #4.

LORENTZ DETUNING MEASUREMENT

The Lorentz detuning measurement was done by the pulse-shortening method during the closed-loop RF operation to keep the stable accelerating gradient in the flat-top region of RF pulse. As one feature of the STF-type cavity, it has more stiffness by the thicker titanium endplate than the TESLA cavity [8]. In the higher gradient operation above 31.5 MV/m, the detuning frequency by the Lorentz force becomes much smaller, and therefore, it is more easily to do the cavity operation by the LLRF control in such higher gradient.

Figure 4 shows the result of LFD for every cavity from S1-Global to STF-2. Although there is little difference in

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the rise-up region, the STF-type cavity has more stiffness than the TESLA cavity in the flat-top region. And, the result for the STF-2 cavities is almost same.

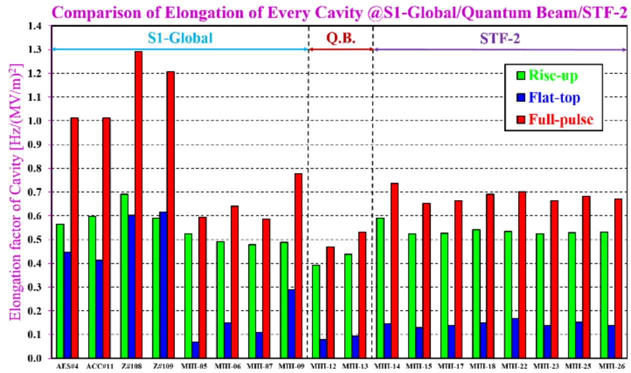

Figure 4: Comparison of the LFD from S1-Global (w/ four TESLA cavities) to STF-2.

VECTOR-SUM OPERATION

The vector-sum operation with eight cavities was done at the average accelerating gradient of 31 MV/m by the feedback and the feedforward RF system. The piezo actuator worked for the compensation of LFD. Figure 5 shows the status of the vector-sum operation with eight cavities at 31 MV/m. The accelerating gradient for each cavity is shown in red. Two of eight cavities, Cavity #1 and #2, achieved around 36 MV/m, and on the other hand, three of eight cavities, Cavity #4, #10, and #12, had more significant degradation in the 3rd cool-down test, as previously described. However, the LLRF control system perfectly worked to keep the stable operation at 31 MV/m for one hour. This means that the STF-2 cryomodules were stably operated at the ILC specification, and it is an extremely important milestone for the realization of ILC.

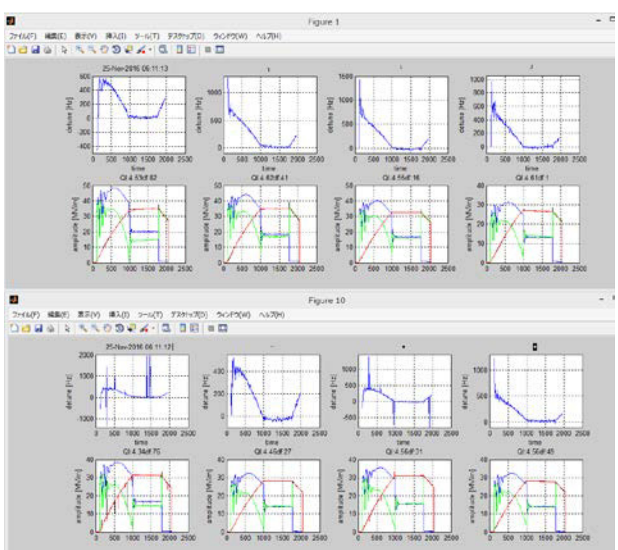

Figure 5: Status of vector-sum operation with eight cavities in the STF-2 cryomodule. The detuning frequency (blue), accelerating gradient (red), forward power (blue), and reflect power (green) are shown.

CONCLUSION

The STF-2 cryomodule has experienced the cool-down tests three times since 2014. In the third cool-down test, the vector-sum operation with eight cavities was successfully done at 31 MV/m, as the extremely important milestone for ILC. As for the lower unloaded Q than the vertical test, the cool-down rate of the STF-2 cryomodule will be faster for the higher unloaded Q in the next cool-down test.

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