HIGH GRADIENT CAVITY PERFORMANCE IN STF-2 CRYOMODULE FOR THE ILC AT KEK

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Abstract

STF-2 Cryomodule for the ILC has experienced cool-down tests twice since 2014 in STF (Superconducting RF Test Facility), and one for low power test and the other for high power test. In this paper, the high power test result will be presented, and the cause of the performance degradation discussed.

INTRODUCTION

After the Quantum Beam project in 2012 [1], construction of the STF-2 cryomodule (one and half size cryomodule, called CM1 and CM2a) started to establish fundamental technology for SRF including beam operation as described in TDR [2] for the ILC [3]. Complicated methods were taken for cavity string and cryomodule assembly, because of small clean room and tunnel hatch in STF. The construction was completed in 2014 after authorization of high pressure gas code in Japan. As already described in [4, 5], vertical tests (V.T.) for twelve cavities, cavity string assembly and low power test during 1st cooldown were done. In the following sections, detailed results from high power test during 2nd cooldown in 2015 will be described.

COUPLER CONDITIONING AT ROOM TEMPERATURE

RF conditioning for twelve input couplers was done in room temperature to suppress outgassing effect before cool-down of STF-2 cryomodule. The RF pulse width was changed at four steps, that is, 20μs, 100μs, 500μs, and 1500μs (five steps, 10μs, 30μs, 100μs, 500μs, and 1500μs at test bench). Figure 1 shows the result of conditioning time. Last four couplers (Coupler #9 − #12) had the longest conditioning time, however, they had the shortest time at test bench.

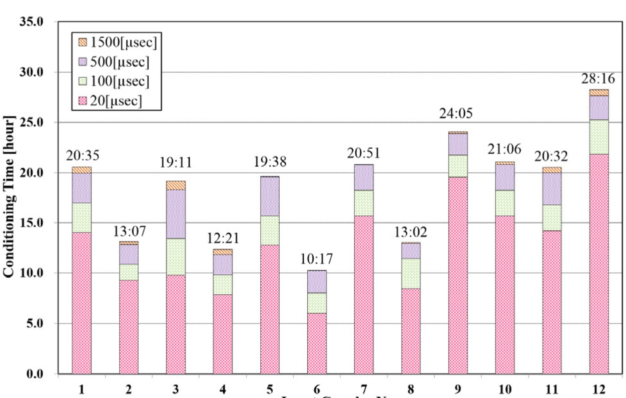

Figure 1: Summary of conditioning time for twelve input couplers in room temperature.

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RF PROCESSING IN CAVITY

After cooldown of cryomodule to 2K, the RF conditioning for twelve cavities started from short pulse (800μs of fill time/100μs of flat-top) at first, and after that, moved to full pulse (800μs of fill time/800μs of flat-top) in the end. The RF conditioning was carefully done monitoring radiation level, heating and RF outputs at HOM (Higher Order Mode) couplers. When RF processing started in cavity, HOM coupler frequently had unusual heating and RF output in each RF pulse. On the other hand, the radiation level, measured at three locations near cryomodule as shown in Figure 3, showed rapid increase or decrease repeatedly, and turned to some intensity in the end. Similarly, unusual heating and RF output at HOM couplers gradually disappeared. Figure 2 shows one-day-trend-graph of cavity conditioning at 2K, that is, forwarded power, accelerating gradient, temperatures at both HOM couplers in left figure, unusual output from HOM coupler #1 in one shot by oscilloscope in right-up, and x-rays measured at three locations in right-down figure. It typically took around 20 hours to do the RF conditioning for each cavity. When the RF processing starts, it is important to keep some gradient level till unusual heating and RF output at HOM couplers disappears completely.

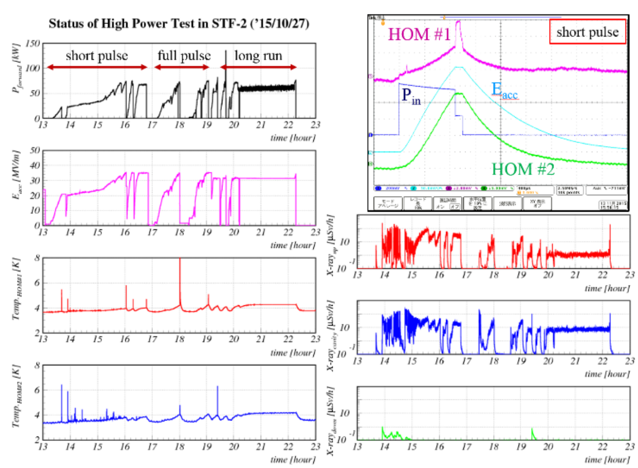

Figure 2: Trend graphs for forwarded power, accelerating gradient, and heating at both HOM couplers during RF processing by short and full pulse in cavity at 2K (left), one shot at unusual output from HOM coupler #1 in oscilloscope (right up) and x-rays measured at three locations near cryomodule (right down).

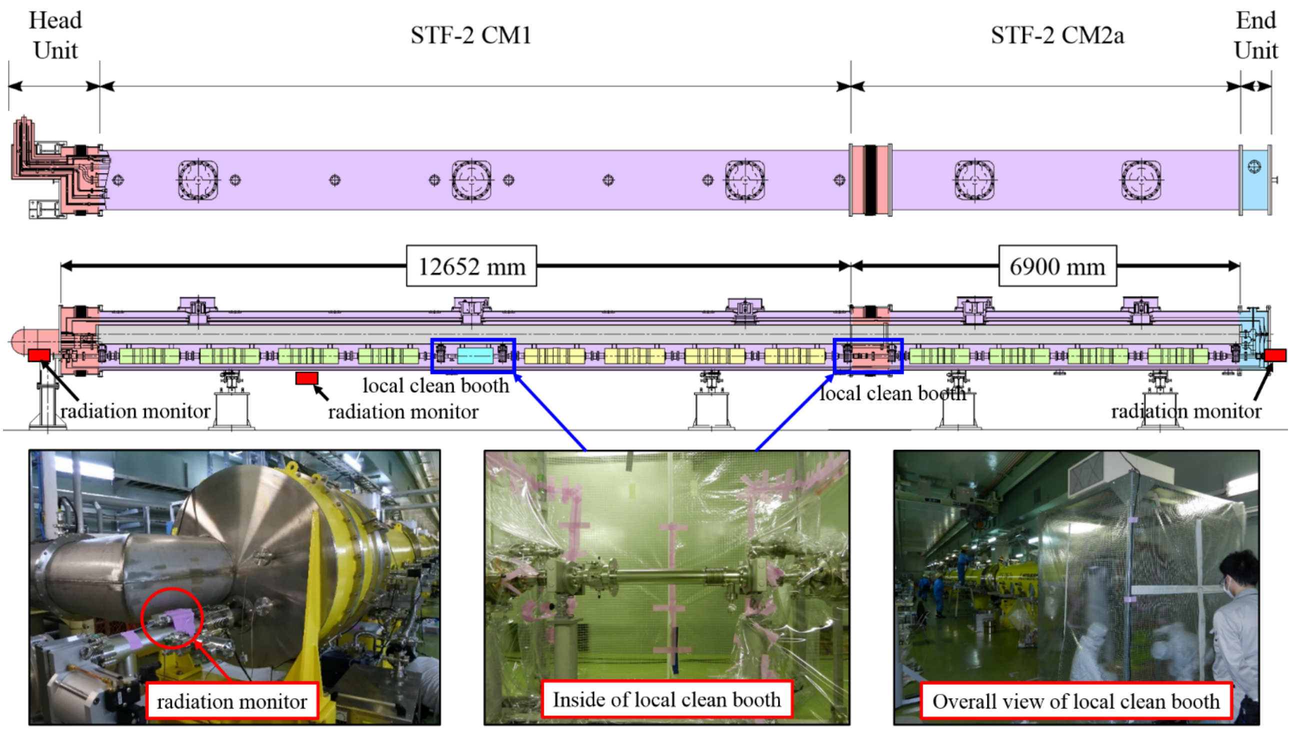

Figure 3: Schematic views of STF-2 cryomodule (top), location for radiation monitor at upstream of cryomodule (bottom left), and local clean booth in tunnel (bottom centre and right). In the top figure, three red filled squares show the locations for radiation monitor. The local clean booth was used for the connection of each cavity string in the tunnel, shown as two blue squares.

CAVITY PERFORMANCE AND RADIATION LEVEL

After RF processing for each cavity, cavity performance (only maximum accelerating gradient) was checked by short and full pulse. Figure 4 shows the result of cavity performance in cryomodule test (C.T.). Cavity string #1 and #3 had no performance degradation, however, cavity string #2 had significant degradation (Cavity #5, #6 and #7). The cause for the performance limit in these three cavities was heavy field emission, and enormous heat loss. Consequently, 8 of 12 cavities achieved above 31.5 MV/m as the ILC specification in C.T. Cavity #1, #4, #5, #8 and #9 were limited by administration stop. Cavity #6 had quench by enormous heat loss in full pulse before x-rays emission, and by heavy field emission in short pulse. Cavity #9 might have significant problem during the fabrication process, because sputtered ball was observed at somewhat away from equator region in cell #9. And, those cavities from cavity #9 to cavity #12 were fabricated by mass production scheme (some processes at electron beam welding were drastically changed) in a vendor [6].

Figure 5 shows the radiation level measured at beneath cryomodule. The position of radiation monitor was changed to beneath measuring cavity for each cavity measurement. Every cavity except Cavity #6 showed field emission in short and full pulse. The radiation level for Cavity #10 and #11 has a kink around 23 – 25 MV/m, and probably, the reason is electron trajectories drastically changes with higher and higher accelerating gradient.

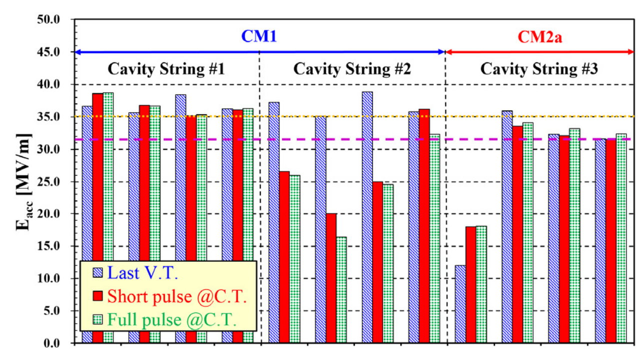

Figure 4: Cavity performance in STF-2 cryomodule. The dotted line at 35.0 MV/m and dashed line at 31.5 MV/m show the ILC specification in V.T. and C.T., respectively.

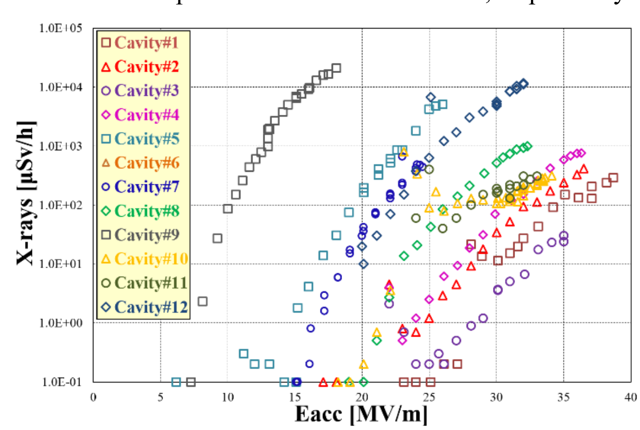

Figure 5: Radiation level measured at beneath cryomodule. Cavity #6 had quench by enormous heat loss.

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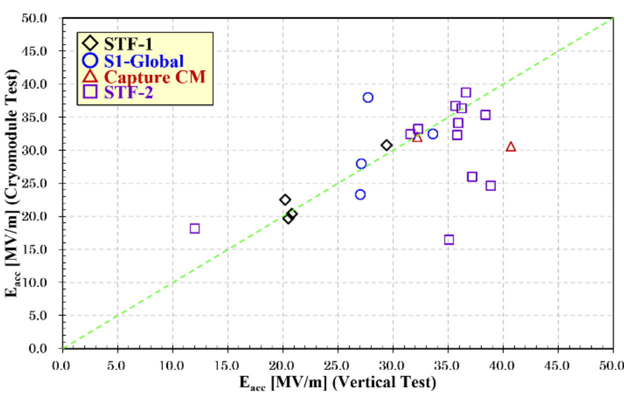
PERFORMANCE DEGRADATION

Three cavities degraded by heavy field emission are connected successively in cavity string #2 in CM1 as shown in Figure 4. Therefore, it is considered the performance degradation was generated by common cause. During cavity string connection in local clean booth as shown in Figure 3, some irregular works were done, and possibly, those cavities might be contaminated by many dust. The content of irregular works is the followings:

- Use of local clean booth as shown in Figure 3
- Exchange of metal valve near cavity string #2
- Extra argon gas purging at gate valve opened

Figure 6 shows the comparison of maximum accelerating gradient in V.T. and C.T. (top), and average accelerating gradient as each cavity string (bottom) for all of cryomodules tested in STF. There are two types for performance degradation. One is gradient drop by heavy field emission (three cavities in STF-2), and the other is gradient drop without radiation (one cavity in Capture CM with two cavities installed). There is no simple explanation for the latter case. For suppression of performance degradation by heavy field emission, it is necessary to change to local clean booth with higher specification, and to improve assembly techniques for cavity string connection.



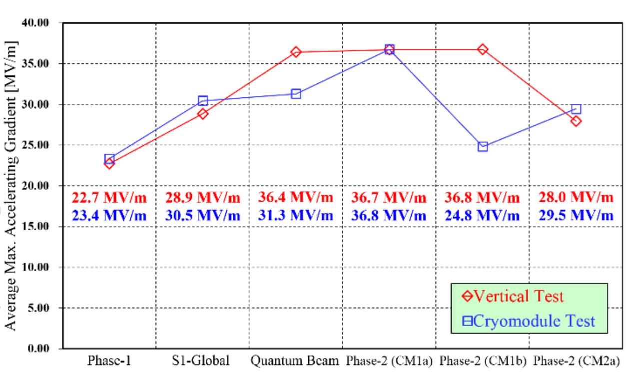


Figure 6: Comparison of cavity performance between V.T. and C.T. (top), and average gradient as each cavity string with four cavities (bottom). Quantum Beam cryomodule (Capture CM) has only two cavities. There are totally four degraded cavities, one in Capture CM and the others in STF-2. There was no performance degradation for Phase-1, S1-Global, CM1a and CM2a in Phase-2.

CONCLUSION

The STF-2 cryomodule has constructed, and experienced two cooldown tests. During the RF conditioning at 2K, it is important to carefully monitor unusual heating and RF output at both HOM couplers, and radiation level. Consequently, the performance of input couplers was no problem, however, three cavities in cavity string #2 had significant performance degradation, possibly by some irregular works during cavity string connection in the local clean booth. It is necessary to improve some assembly tools and techniques in future.

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