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IMPROVEMENT OF A CLEAN ASSEMBLY WORK FOR SUPERCONDUCTING RF CRYOMODULE AND ITS APPLICATION TO THE KEK-STF CRYOMODULE

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Abstract

We usually encountered the degradation of the superconducting RF cavities on the cryomodule test even though the performances of these cavities were good on the vertical test. In reality, the degradation of Q-values of two cavities of cERL main-linac were observed after cryomodule assembly in KEK [1] and STF cryomodule also met the degradation after the cryomodule assembly [2]. Some dusts and invisible particles might enter the cavity and generate field emission during the assembly work. Field emission is the most important cause of this degradation. In this paper, at first we introduce some improvements of the clean assembly works to SRF cavity by re-examining our clean assembly work and vacuum work. For example, slow pumping system with vacuum particle monitor was developed to know and control the particle movement during slow pumping and venting. Next, we show the application of this improved work to the STF re-assemble cryomodule work in KEK.

INTRODUCTION OF STF CRYOMODULE

STF cryomodule was constructed to demonstrate to establish the fundamental technology for Superconducting RF cavities with beam operation for the ILC [3]. STF cryomodule consists of a capture cryomodule, and a STF-2 cryomodule. The STF-2 cryomodule includes twenty 1.3 GHz 9-cell TESLA-like cavities as shown in Fig. 1. The construction of STF-2 cryomodule was completed in 2014 after authorization of high pressure gas code in Japan. As already described in Ref. [4], vertical tests (V.T.) for twelve cavities, cavity string assembly and low power test during 1st cooldown were done. And high power test during 2nd cooldown in 2015 were described in Ref. [2].

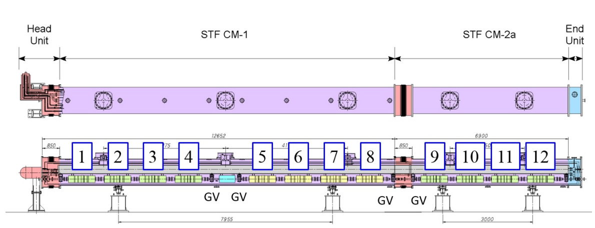

Figure 1: Layout of STF-2 cryomodule. Numbering of cavities are also described in STF-2 cryomodule.

Complicated methods were taken for cavity string and STF-2 cryomodule assembly, because of a small clean room and tunnel hatch in STF. We briefly summarize the assembly work after the vertical tests and those results in this part. First, the 4 cavities were connected in series for string assembly in an ISO class 4 (class 10) clean room after the vertical tests. The two 4 cavities that had been transported into the STF tunnel were connected in a local clean booth, and these eight cavities that constituted the CM-1 part, as shown in Fig. 1, were completed. After string assembly of another 4 cavities in a class 10 clean room and installing these cavities to the cryostat CM-2a part as shown in Fig. 1, the CM-2a was transported into the STF tunnel and was installed in downstream of the CM-1. Finally, CM-1 part and CM-2a part were connected in a local clean booth as STF-2 cryomodule. And high power test were performed by using STF-2 cryomodule. Unfortunately, three cavities of #5, #6 and #7 as shown in Fig. 1 degraded by heavy field emission [2]. During cavity string connection in a local clean booth at STF tunnel, some irregular works were done, and possibly, those cavities might be contaminated by many dusts. The contents of irregular works are the followings:

- Use of a local clean booth without laminar flow
- Sudden extra argon gas purging when the gate valve opened.

Sudden purging was done when the gate valve opened between #4 and #5 cavities as shown in Fig. 1. We note that the gate valve between #8 and #9 cavity did not open. In 2019, we planned beam operation by using STF-2 cryomodule [5]. We worried that the degradation would occur again after opening GV between #8 and #9 due to the poor assembly work with a local clean booth and vacuum work as described above. It is necessary to improve our clean assembly work not to degrade the cavity performance. Therefore we decided to reassembly work between CM-1 part and CM-2a part in STF-2 cryomodule by improving the local clean booth with higher specification, and assembly techniques for cavity string connection and vacuum work.

In this paper, we describe the improvement works of clean work at a local clean booth and vacuum work and show the actual application to STF-2 cryomodule by using this improved clean work method.

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IMPROVEMTS OF CLEAN ASSEMBLY WORKS

New Local Clean Booth

In order to improve our local clean booth, we prepared new clean bench. Figure 2 shows the schematic view of our new local clean booth by using new local clean bench named as KOACH [6], which should be compared with previous clean assembly work [2].

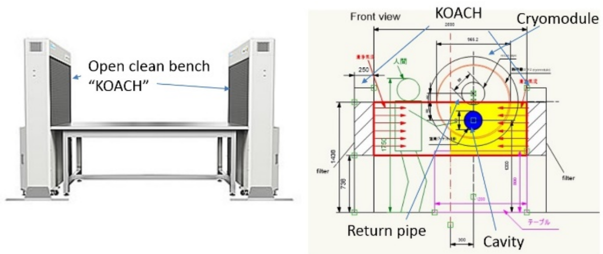

Figure 2: (Left) the open clean bench "KOACH". (Right) Conceptual design of new local clean booth for STF-2 cryomodule. Yellow area is estimated to give ISO class 1 clean environment by using KOACH.

The KOACH makes ISO class 1 clean environment with the original filter and laminar flow. A very clean area of ISO class 1 is made by the filters facing each other even though this clean area is not covered by some clean sheets. This is the concept of this KOACH and some clean room for superconducting cavity is made by this KOACH [7]. The right figure of Fig. 2 is our conceptual design for making a local clean booth by using KOACH. Unfortunately, we did not get the clean laminar flow on the previous clean assembly work because the return pipe of the crymodule obstructed making the laminar down flow at the cavity region. Side laminar flow created by KOACH makes clean environment at cavity region. In addition, we found that the encountered flow kept clean at a half side of this clean area even though the worker stood at another half side in this clean area as shown in the right figure of Fig. 2 [8]. Therefore, the half area of this clean area fully covered the cavity region as shown in the right figure of Fig. 2.

Slow Pumping and Venting System

Figure 3 shows the pictures of our slow pumping and venting system. Figure 4 shows the schematic diagram of slow pumping and venting system for a superconducting cavity. The pumping system is similar to the pumping system which was used on EURO-XFEL construction [9]. However, the vacuum particle monitor [10] was equipped to measure the particulates under pumping and venting in our system. Furthermore, all valves were manually controlled to slowly move the gate valve. This is necessary not to produce particulate by moving the gate valve [11]. Slow pumping and venting speed was controlled by mass flow meter. During slow pumping, the mass flow meter controlled the flow via the bypass line with small pipe. When the pressure reached to less than 100 Pa, the pumping line changed to the main pumping line with large diameter of 40 mm to obtain sufficient conductance and finally the cavity vacuum was pumped by Turbo Molecular Pump (TMP). Nitrogen gas was used for slow venting and the diffusers were set on the slow venting line. The pressure was measured by an ion crystal gauge. Dynamic range of the vacuum particle monitor is from 0.3 µm to 3.6 µm. The slow pumping speed is typically 0.6 l/min and venting speed is 0.2 l/min.

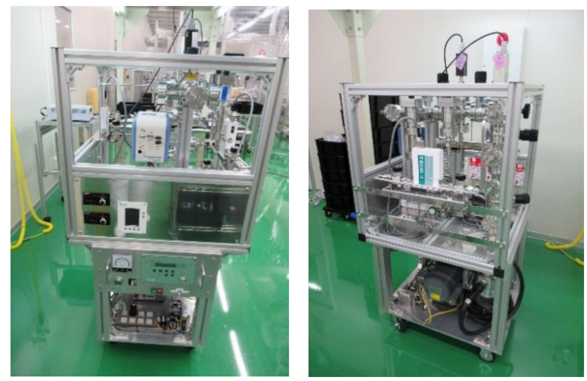

Figure 3: Picture of slow pumping & venting system.

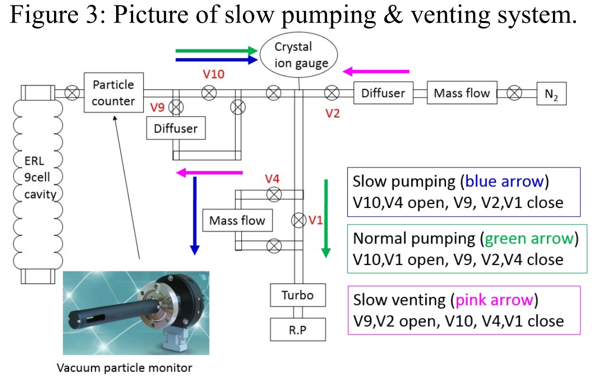

Figure 4: Detailed block diagram of slow pumping & venting system with 9cell cavity and valve assign (red).

STF-2 CRYMODULE REASSEMBLY WORKS AFTER IMPROVEMENTS

Figure 5 shows the actual configuration during the cryomodule reassembly work between CM-1 part and CM-2a part. Figure 6 shows the detailed setup of new clean booth beside the STF-2 cryomodule with slow pumping and venting system as shown in Fig. 5.

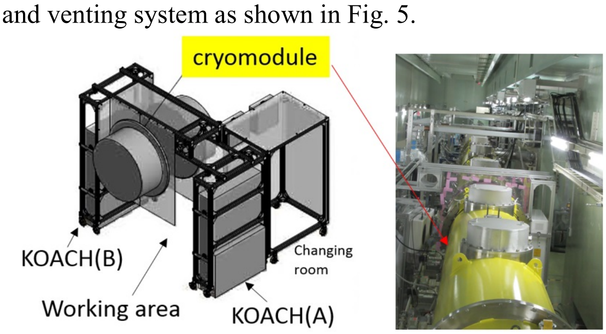

Figure 5: Actual configuration during the cryomodule reassembly work between CM-1 and CM-2a.

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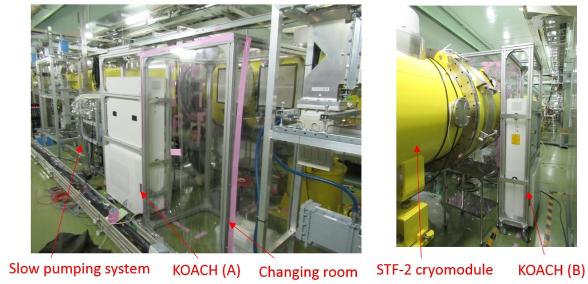

Figure 6: Detailed setup of clean booth in Fig. 5.

There is a bellows between CM-1 and CM-2a in STF-2 cryomodule. The vacuum of bellows was isolated by the gate valves of CM-1 and CM-2a. Our aim of this reassembly work is to reinstall this bellows after cleaning up by ultra-pure water rinsing again.

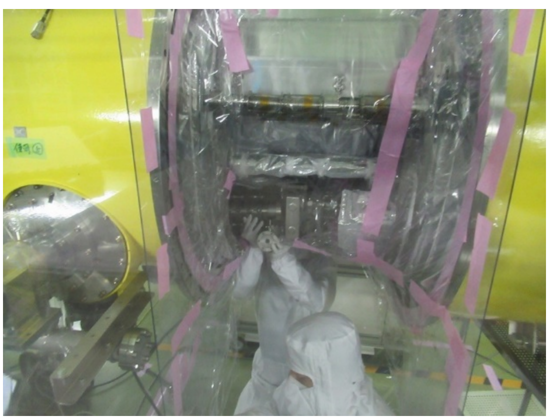
Figure 7: Reassembly work of bellows in STF-2 cryomodule

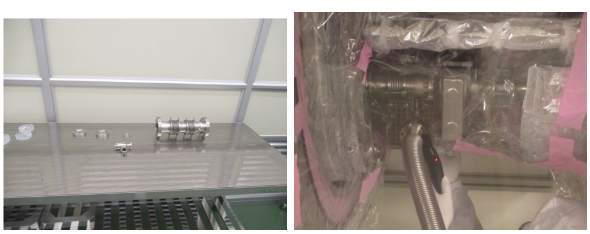
Figure 8: (Left) Dried bellows in a clean room. (Right) Clean work in a local clean booth by using ionized gun.

Figure 7 shows the reassembly work of bellows at new clean booth. Around this area, all cryomodule components except for bellows were covered by the antistatic soft vinyl chloride film and/or plate to keep ISO class 1 environment created by KOACH. One person supported the bellows under the cryomodule and another person approached from KOACH (A) side to disconnect the screws of bellows. The flow from KOACH (B) side kept clean laminar flow at the bellows position under reassembly work. After the removal of bellows, this bellows and necessary vacuum components were rinsed by ultra-sonic cleaning with ultra-pure water and dried for one night in class 10 clean room as shown in Fig. 8 (left). Finally the bellows was reconnected to the both gate valves. During this clean assembly work, all screws and holes of flange were fully blown by the ionized gun as shown in Fig. 8 (right).

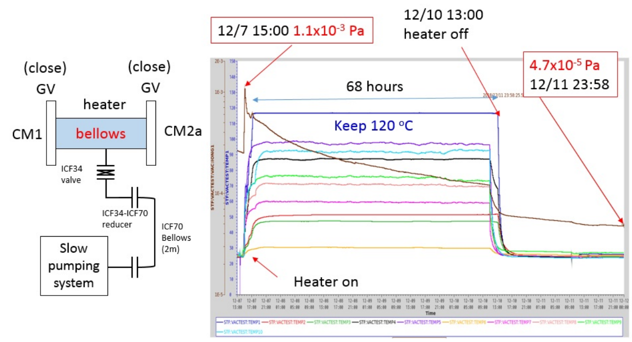

Figure 9: Setup of slow pumping of bellows (left) and its pumping results under baking (right). Brawn line shows the vacuum pressure and other lines shows the measured temperatures at slow pumping line. Blue line shows the temperature at bellows.

Next, we pumped this bellows by using slow pumping and venting system. Figure 9 shows setup and its results during pumping by using slow pumping system. After 68 hours baking at 120 °C, vacuum pressure reached to 4 x 10^{-5} Pa.

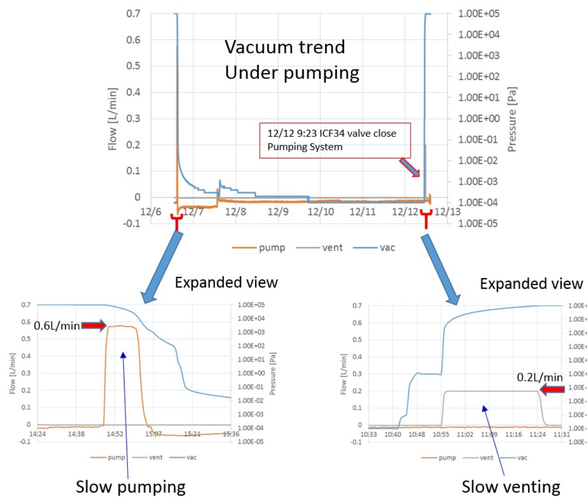

Figure 10: (Top) Vacuum pressure and flow rate history under baking of bellows. (Bottom left) Expanded view when we start slow pumping (Bottom right) Expanded view when we start slow venting. Under venting, the ICF34 valve have already closed.

We worried whether the particulates come into the cavity or not under pumping. We measured the particulates moving to the bellows by using the vacuum particle monitor under pumping as shown in Fig. 9. Figure 10 shows the flow rates under slow pumping & venting. When we started pumping the inside of bellows as shown in Fig. 9, we could pump slowly by using this slow pumping system. Measured flow is stably controlled to 0.6 l/min by using mass flow controller at first. It took 40 min. to 100 Pa. After reaching 100 Pa, we changed the normal pumping by changing the GVs in slow pumping system. Finally we reached around 10^{-5} Pa level as shown in Fig. 9. We note that we could control not only pumping but also venting by using this system. The right bottom figure in Fig. 10 shows the measured flow under slow venting by nitrogen gas to

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bellows. Flow ratio is controlled to 0.2 l/min flow under venting. By using this slow pumping & venting system, we could escape the sudden purging and pumping as we already met on the previous assembly work.

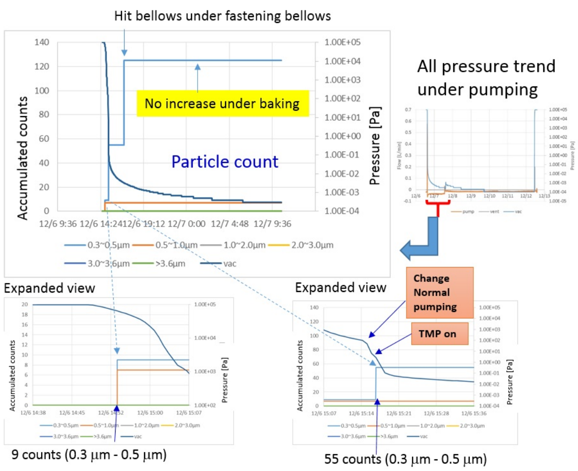

Figure 11: (Top right) vacuum pressure and flow rate history under baking of bellows. (Top left) The measured accumulated particle counts when we start slow pumping (Bottom left) Expanded view of top left figure. (Bottom right) Expanded view of top left figure under changing normal pumping and TMP on.

Figure 11 shows the results of the measured accumulated particle counts by the vacuum particle monitor during pumping. Unfortunately, we found that the measured particles three times increased. First the measured dusts of size between 0.3 μm and 0.5 μm increased by 9 counts under slow pumping. Second, the measured dusts of size between 0.3 μm and 0.5 μm increased by 46 counts when we turned on TMP after changing normal pumping. We note that we did not observe increasing event of particles under changing slow pumping to normal pumping by changing GVs because we slowly controlled GV. Dusts was not produced from GV. However, dusts come from TMP itself. Third, the sudden particle events was found as shown in the top left figure in Fig. 11. At this time, we fastened the flange of slow pumping line. This work made the measured particles increased. Totally, 125 counts with size between 0.3 μm and 0.5 μm was found when we start slow pumping. During baking around 3 days and under cooling down this bellows, we never found the increasing event of particles by this vacuum particle monitor. We note that the particle increasing was not found under slow venting thanks to the slow flow rate of 0.2 l/min by mass flow controller. Finally, we closed the ICF34 gate valve as shown in Fig. 9 and opened the GVs between CM-1 and CM-2 to complete the vacuum work.

After cooling down of STF-2 cryomodule for beam test, we did not meet the severe field emission of these cavities. Finally, the cavity field kept more than 32 MV/m during beam operation, which is our target of ILC cryomodule [5]. We mentioned that this new local clean booth and slow pumping and venting system used not only for cryomodule reassembly work as described above but also for the beam line construction beside the STF-2 cryomodule. Our improved clean assembly work will help to escape from severe field emission. Therefore, this slow pumping and venting system was used for another cryomodule assembly work [12].

SUMMARY AND FUTURE PROSPECT

In order to reassemble the STF-2 cryomodule, we improved the clean assembly works. New clean bench named as KOACH was prepared and optimized to STF-2 cryomodule reassembly work. The slow pumping and venting system was developed not to make big turbulence, which would make the dust come into the cavity, during pumping and venting. Furthermore, the vacuum particle monitor was prepared to monitor the particulate movement to the cavity. By improving these clean works, the reassembly of the bellows between CM-1 and CM-2a was carried out under fully clean environments, The dusts moving to the cavity was drastically suppressed by using this slow pumping and venting system. After the reassembly work, we successfully achieved more than 32 MV/m average gradient of seven cavities in STF-2 cryomodule. In 2020, we plan to install new cavity to STF-2 cryomoodule. These improved clean works will also help to keep sufficient high gradient performance in STF-2 cryomodule.

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