BASIC RESEARCH ON HORIZONTAL ASSEMBLY METHOD OF SC CAVITIES WITH HIGH Q AND HIGH GRADIENT

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Abstract

The fabrication technology of the high gradient superconducting(sc) cavities has been made much progress in the last 10 years. As a next issue, one has to develop a horizontal assembly method of sc cavities which makes no performance degradation in order to exhibit the excellence in the accelerator. Among many candidates of the cause with the degradation, here, the influence of breaking cavity vacuum after the vertical test and indium contamination effect are investigated.

1 INTRODUCTION

By the R&D of high gradient sc niobium cavities done at KEK so far, its technology level has come to the high gradient of 30 - 40 MV/m. Our next R&D target is to realize the excellence in the horizontal cryomodule. Performance of the sc cavity is very sensitive to the surface contamination, so generally speaking it is hard to reproduce the performance of the vertical test in a real accelerator. Really in the TRISTAN sc project, we observed a degradation in both Q value and the maximum accelerating gradient (Eacc,max) by the horizontal assembly. If the same degradation happens in the future advanced sc applications, the effect is very serious because the machines will be operated at 2K. The study of assembly method of cryomodule is an essential R&D issue.

2 HORIZONTAL ASSEMBLY

2.1 Horizontal assembly

In the TRISTAN sc project, after the vertical test of individual cavities, the cavity vacuum was broken introducing pure(6-N) and particle free (> 0.01 μm) nitrogen gas into the cavity for one night, then end flanges at the beam tubes were opened in the class 100 clean room and the remained scraps of indium used for the vacuum sealing on the flanges were carefully cleaned up. Two cavities were paired at the end flange of the beam tube with indium seal again. Blanket extension tubes were joined to each cavity at the other beam tube. After that, blanket flanges on the HOM ports were taken off and cleaned up indium scraps on the ports, then put on HOM couplers on them. The paired cavities were installed in the helium vessel of the horizontal cryostat outside of the clean room, then input couplers were put on the each port under a clean environment which was produced by a portable small clean booth. While this work, nitrogen gas was flowed the pair to prevent particle contamination from the outside. Then all the parts were assembled on the cryostat.

2.2 Degradation of cavity performance

After the horizontal assembly, the cavity pair was evacuated and cold tested. The unloaded Q value (Qo) was scattered after the horizontal tests and degraded in average as: 2.7×10^9 (vertical)→1.7×10^9 (horizontal).
This means that a surface resistance of 60 nΩ was added.
$E_{acc,max}$ was also decreased as:
10 MV/m (vertical)→7 MV/m (horizontal).
However, the cavity performance in the accelerator did not change from the horizontal test.

2.3 Possible causes for the degradation

The degradation happens in the future application of sc cavities like a sc proton linac or TESLA, the influence is very serious. For instance, JAERI is considering a sc proton linac (600 MHz) for an intensive neutron source for the neutron science and nuclear waste transmutation. For this machine, electric power efficiency in the operation is an important issue, therefore 2 K operation will be applied. In this case the typical surface resistance of the cavities is about 10 nΩ. Adding 60 nΩ by the horizontal assembly, Qo value takes a figure down so that there is no meaning of the 2 K operation. The field degradation is also very serious for the machine. It is to be operated at Ep = 16 MV/m (surface peak field). The field limitation of 7 MV/m corresponds to 14 MV/m in Ep. There is no way for the operation.

One has to take a cure to prevent the degradation if he use the same assembly procedure. The possible causes of the degradation will be followings: 1) influence of breaking cavity vacuum, in other words particle contamination, or oxidation of niobium surface while the horizontal assembly, 2) indium contamination, 3) absorption gas, 4) contamination problem from RF accessories like input coupler or HOM couplers, 5) field emission, 6) multipacting so on. In this paper we investigate qualitatively used L-band single cell cavities with higher sensitivity on the issues 1) and 2) among these candidates.

3 INFLUENCE OF BREAKING CAVITY VACUUM

3.1 Effect of introducing N_2 gas

A concerning of breaking cavity vacuum is the particle contamination from the vacuum system or in the used N_2 gas. As a result the residual surface resistance (Rres) might increase or field emission happens. The faster N2 gas flow may bring the more particles into the cavity. In this experiment, flow rate of nitrogen gas was changed from 1.5 cc/min. to 900 cc/min. We used the vacuum evacuation system presented in figure 1. The flow rate is adjusted by the valve(V2). Particles bigger than 0.01 μm size in the gas are eliminated by the final filter. By the particle counter measurement, manipulating of the final valve V2 produces particles, so it has to be handled carefully. The vacuum pressure of the sealed cavity is worse than 2-3 x 10^{-5} torr after the cold test (while cold testing the cavity vacuum is also sealed.). Prior to open the cavity valve V6, the space between V1 and V6 is evacuated to less than 1.5 x 10^{-5} torr, then V6 is opened. By opening V4 very carefully, it is checked whether the cavity was fully filled with N_2 gas. Vacuum evacuation

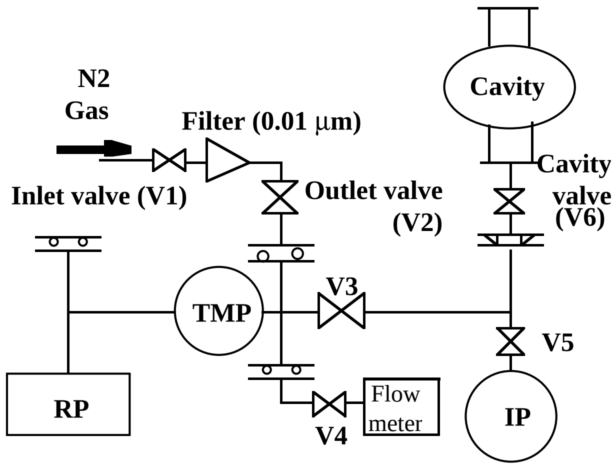

Figure 1: The used vacuum system for N_2 gas leak.

was started as soon as it was filled. Typical results of breaking cavity vacuum are shown in figure 2 on residual surface resistance and in figure 3 on field gradients. The summary is presented in Table 1. The concerned increase of Rres is not observed in the measurement error up to the flow rate of 900 cc/min. A clear field emission was observed from 20 MV/m at the flow rate 5 cc/min. but the other cases were not significant. That might be a mistake in manipulating the valves. Eacc,max decreases a little : 8 - 18%. This influence are too small to explain the degradation in the TRISTAN horizontal assembly.

Table 1: Summary of influence of breaking cavity vacuum with N_2 gas.

Flow rate of N2 [cc/min.]	Rres [nΩ] before / after (difference)	Eacc,max [MV/m] before / after (difference)	F.E at Eacc < 25 MV/m before / after
1.5	14.0 / 11.3 (-2.7)	31.3 / 31.8 (+2%)	No / No
5.0	7.7 / 4.8 (-2.9)	36.3 / 29.7 (-18%)	No / Yes from Eacc = 20
21.5	7.7 / 7.2 (-0.5)	40.3 / 34.2 (-15%)	No / No
120	12.1 / 14.4 (+2.3)	30.9 /28.4 (-8%)	No / No
900	5.4 / 7.4 (+2.0)	31.8 / 32.4 (+2%)	No / No

3.2 Influence of air exposure

Even nitrogen gas was flowed into the cavity while the horizontal assembly, there is a chance for the cavity inner surface to be exposed to the air. In this case, oxidation of niobium surface is concerned. A cavity once exposed to nitrogen gas in the experiment of *3.1* was exposed to the air by the same method as *3.1* for one day to one week

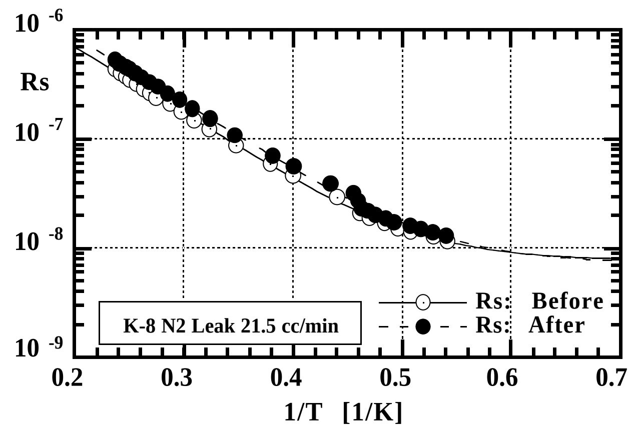

Figure 2: Effect on Rres with N_2 leak.

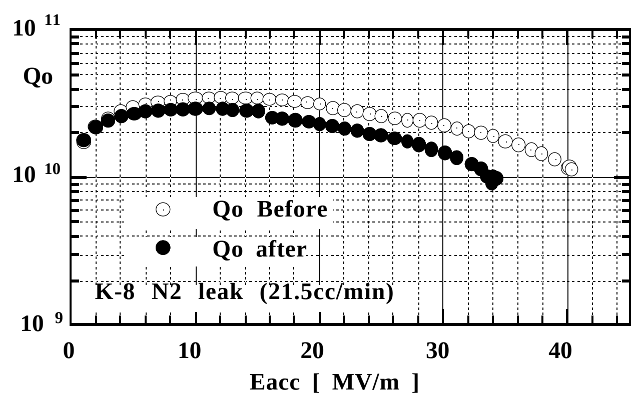

Figure 3: Effect on the Eacc with N2 leak.

Table 2: Summary of the effect of air exposure.

Exposed time	Rres [nΩ]	Eacc,max [MV/m]	F.E. onset field [MV/m]
0	7.4	32.4	29
< 45 min.	8.3	34.2	29
1 day	12.5	32.2	23
3 days	12.3	28.9	23
7 days	16.2	28.0	22

without disassembly. The results are summarized in Table 2. Only introducing the air into the cavity has no influence on Rres and Eacc,max but the exposure for one week produces the additional Rres of 8 nΩ and reduces the gradient by 9 % due to field emission. The onset point of field emission becomes lower with increased air exposure time. The exposure time of one day is enough for the horizontal assembly procedure. The resultant Rres of 5.1 nΩ and Eacc,max reduction of 0 % are too small to explain the degradation in the horizontal assembly. Especially the additional Rres is out of sight in the measurement error at 4.2 K because BCS surface resistance (100 nΩ at 500 MHz) is dominate in this temperature, however, this additional Rres is very serious in the 2 K operation. It reduces the Qo value to about one half. Some cure might be need for this degradation with the 2 K operation.

4 INFLUENCE OF INDIUM CONTAMINATION

KEK has used indium wires or ribbons for the vacuum sealing of sc cavities. It has a high reliability but has a contamination problem by its scraps in disassembly. An experiment to see qualitatively the influence was carried out at CEBAF using a 1.5 GHz single cell cavity. In this experiment a flat indium fragment was attached intentionally on the cavity inner surface at the place 25 mm inside from the iris. The size was changed by four kinds : 35, 1.5, 0.5 mm^2 and no indium. After every measurement, the cavity was disassembled, soaked with nitric acid to eliminate the indium, then taken BCP(1:1:1) with a 30 μm material removal. The indium fragment was attached in the class 100 clean room after the surface treatment. The results are presented in figure 4 with the Eacc vs. Qo, in figure 5 on Rres and in figure 6 on the Eacc,max. Indium produces a big influence on both Rres and $E_{acc,max}$. The additional Rres and reduction of the $E_{acc,max}$ with the indium size (S; mm^2) are estimated from this experiment as follows:

Δ Rres (1.5GHz) =1.12 $\mu\Omega/mm^2$ · · ·(1),

Δ $E_{acc,max}$ = 1 - exp(-S/1.75) · · ·(2).

The thermal valance between a heating at the indium

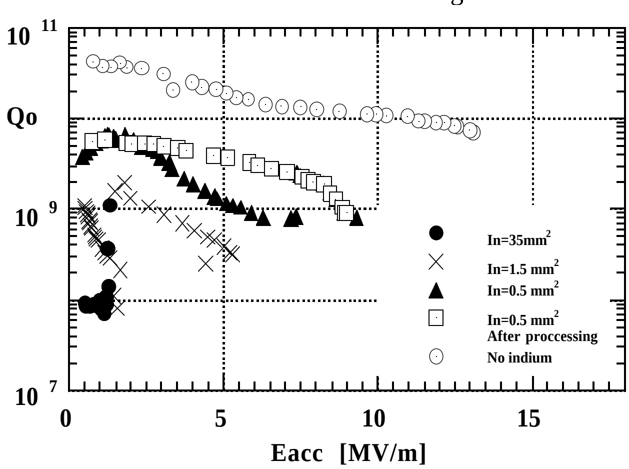

Figure 4: Indium size effect on Qo and Eacc,max.

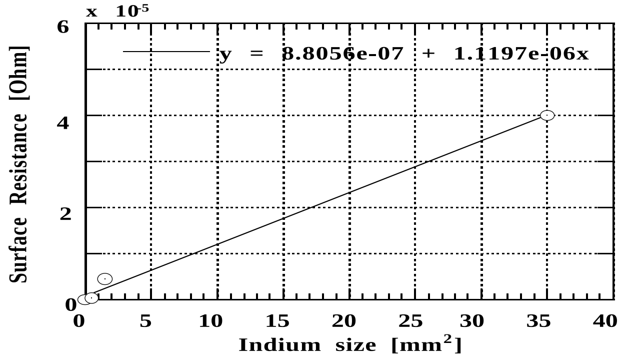

Figure 5: Increased surface resistance with indium size.

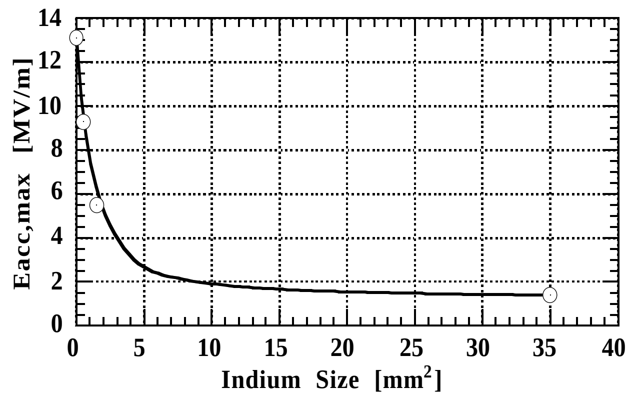

Figure 6: Limitation of field gradient with indium size.

fragment and the thermal conductivity of niobium determines the $E_{acc,max}$. Therefore the $E_{acc,max}$ does not depend on the frequency of the microwave. On the other hand, the sensitivity of the additional Rres of the eq. (1) depends on the rf frequency. For instance, from the definition and the scaling of rf frequency Qo value of 0.5 GHz cavity is presented by the Qo of 1.5 GHz cavity for the same Eacc as following:

$Qo(0.5GHz) = \omega_{1.5}U_{1.5}/(Pc_{1.5} + 1/9\cdot P_{loss}(indium))$.

Here, U is a stored energy in the cavity, ω the angular velocity of microwave, Pc the intrinsic wall loss of the cavity, and Ploss(indium) the heating power at the indium. The 0.5 GHz cavity has the larger surface 9 times than the 1.5 GHz cavity, so the indium effect becomes small relatively to 1/9. Addition to it, the TRISTAN sc cavity is a 5 cell structure. The indium effect of eq. (1) should be changed for the TRISTAN sc cavities as follows:

Δ Rres(0.5GHz) = 1.12/(9x5) $\mu\Omega/mm^2$,
= 25 $n\Omega/mm^2$ (3).

Suppose the reduction of 30% in Eacc,max by the TRISTAN horizontal assembly comes from the indium contamination, the size is about 0.6 mm^2 from eq. (2). Even if such an indium or scraps entered the cavity during cleaning the cavity flanges in the assembly work, it is not strange. The indium adds an additional Rres of 15 nΩ from eq. (3) and finally brings to field emission as presumed from figure 4 (▲ and ❐). A possible explanation of the performance degradation in the TRISTAN horizontal assembly is the indium contamination and the resultant field emission.

5 SUMMARY

Among possible causes of the cavity performance degradation in the TRISTAN horizontal assembly, the influence of breaking cavity vacuum and the effect of indium contamination are investigated. The former is not guilty with the 4.2 K operation but some cure is needed for the 2 K operation. The later has a serious effect on both Qo and field gradient. The degradation can be explained the indium contamination with the size about 0.6 mm^2, however, the other possibility should be investigated like contamination from cavity accessories or multipacting. The research program is now under going at KEK.