

Water Rinsing of The Contaminated Superconducting RF Cavities

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Abstract

Evaluation tests of the water rinsing on the contaminated superconducting cavities were conducted with high pressure water rinsing (HPR) and megasonic rinsing (MSR). It made sure HPR eliminates very effectively the surface contamination. MSR is just started, but the preliminary result seems that it is useful to reduce the field emission over than $E_{acc} = 25$ MV/m. The quality of rinsing water was also investigated. Filtered pure water looks to be usable instead of ultrapure water.

1. Introduction

Elimination of the field emission is an important issue for the high gradient superconducting RF cavities. The active water rinsing technique is very effective against this problem. High pressure water rinsing (HPR) has been recognized as a very powerful tool against field emission since the last SRF workshop at DESY[1, 2]. We had investigated the HPR effect on removing dust particles on the surface. As reported at the last CEBAF workshop, by the sample test using silicon wafers, HPR showed a large effect. However, any difference was not seen in cavity tests by the procedure added HPR to the KEK standard surface treatment[3]. Since then, to see more clearly HPR effect, we have applied it to the contaminated L-band single cell cavities, and investigated how they recover the performance. By this experiment we finally made sure its powerful effect. In the section 2, these results are presented.

As the active rinsing method, megasonic rinsing(MSR) is well known in the semiconductor technology[4]. This method looks easier than HPR for the cavity application. By our sample test with silicon wafers, it seemed more effective than HPR[3], and that motivated us to see its effect on the cavity performance. At the first step, we have just used a megasonic bath rinsing. As the second step, we have developed a inserted type in order to radiate directly the megasonic sounds on the inner cavity surface. The test using these equipment is going now. The preliminary results are shown in the section 3.

We have recognized the powerful HPR effect against field emission, however, it requires a large amount of ultrapure water for multi-cell

cavities. The capability of our ultrapure water system limits the HPR rinsing time around 1.5 hours, which is not enough for 9-cell cavities. If the filtered "pure water" is usable to HPR, this difficulty is easily resolved because our pure water system has an enough capability (> 1 Ton / hour). This problem let us investigate the quality of rinsing water. The results are presented in the section 4 .

In the last section, we discuss multipacting with the processing levels appeared at 15 - 20 MV/m in our Q_0 - E_{acc} measurements.

2. Effect of the high pressure water rinsing

1) Performance recovery of the contaminated cavity by disassembling

One cavity was disassembled and left in the class 100 clean room after the cold test. 1.5 months later, it was tested again without any surface treatments to see the base performance. The result is presented in Fig.1 (mark;●). The Q_0 values were very low, and the field gradient was limited to 11 MV/m by the heavy field emission. One reason of this bad performance is indium or dust contamination during disassembly.

After this cold test, it was treated with HPR (85 kg/cm², 1 hr, by 0.2 μ m filtered pure water) and a light shower rinsing (ultrapure water). As shown in Fig.1 (mark; ○), comparing the original good performance (reference; x), one can see the performance was recovered by this treatment. This experimental result means HPR can eliminate the surface contamination during cavity disassembling, and we do not need any additional chemical process to remove the dust contamination.

From this result, one will have an idea about cavity assembly method. If one takes HPR whole the cavity module on which all the cavity accessory (input / HOM couplers, so on) is, the dust contamination problem during cavity / cryomodule assembly could be eliminated, even the present cryo-structure has to be redesigned in order to stand it for the HPR.

2) Elimination of the final chemical treatment after annealing

To see the contamination by annealing, one cavity was annealed for 5 hours at 800°C under the vacuum pressure of $\sim 10^{-6}$ torr, and immediately measured without any treatments. The result of the cold test is shown in Fig. 2 (mark; •). The field gradient was limited to 10 MV/m by the heavy field emission. After this test, it was rinsed with water megasonic bath rinsing (950 KHz, 30 min.) in the KEK class 10 clean room. However, the cavity performance did not improve so much (mark; ○). The field gradient was limited to 12.5 MV/m due to the heavy field emission. Then it was rinsed with HPR (1 hr, by 0.2 μm filtered pure water) and a light shower rinsing (ultrapure water). The cavity performance has upgraded remarkably (mark; x), and reached the high gradient of Eacc = 30 MV/m.

This experimental result concludes that HPR can remove the surface contamination in the annealing procedure. We have no additional chemistry to remove such a contamination, and just HPR is enough.

3. Megasonic rinsing effect

1) Possible elimination of the field emission over than 25 MV/m

Two L-band single cell cavities were tested to investigate the megasonic rinsing effect on the cavity performance. After a light chemical polishing (30 μm), cavities were immersed in the megasonic bath (50 °C, overflowed ultrapure water), and agitated for 30 minutes (600W). A reflector made of crystal glass was set in the cavity in order to reflect the megasonic sound coming from the lower beam tube to the cavity inner cell surface; called as reflection type. After this rinsing, the cavity was rinsed with HPR (1 hr, by 0.2 μm filtered pure water) and the light shower rinsing (ultrapure water). This result is shown in Fig.3 (mark; ○). Comparing the megasonic rinsed result to the non megasonic rinsed result (mark; •), one can see a better tendency in the former against Q_0

decreasing over than 25 MV/m. If we take a more powerful megasonic rinsing method (inserted type) instead of reflection type, the field emission over than 25 MV/m might be perfectly eliminated.

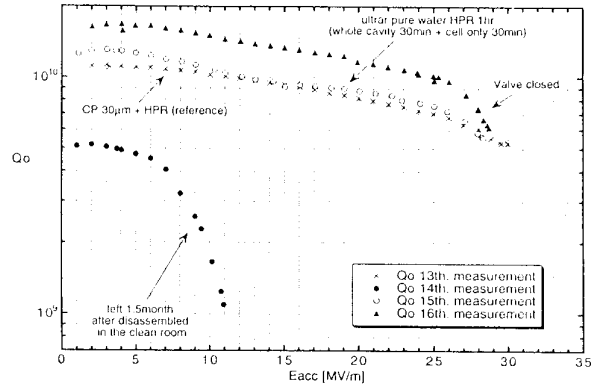


Fig. 1. HPR effect on the contaminated surface during disassembling.

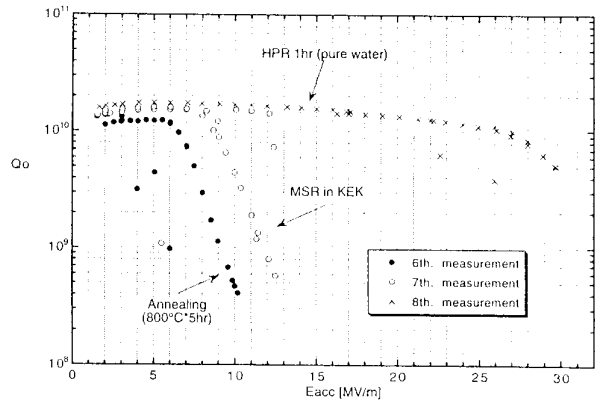


Fig. 2. HPR effect on the contaminated surface by annealing.

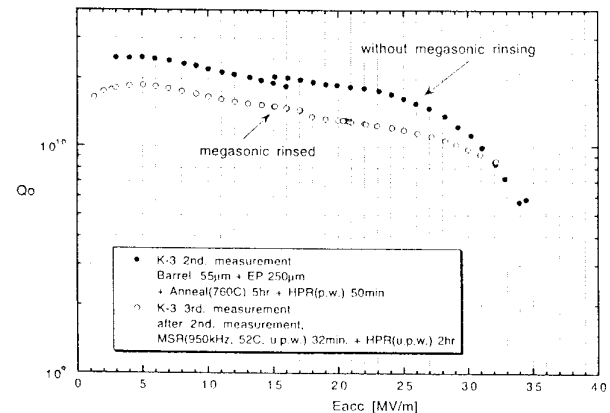


Fig. 3. Effect of megasonic rinsing (with reflection type).

2) Excellent reducing particle power by the inserted type

With the above expectation, we have just developed a new megasonic oscillator which can directly irradiates the megasonic sound on the inner cell surface for the L-band single cell cavities; called as the inserted type (600W). This new oscillator is shown in Fig. 4. Presently we are researching the rinsing condition with this oscillator and a liquid particle counter at the outlet of the overflowing water.

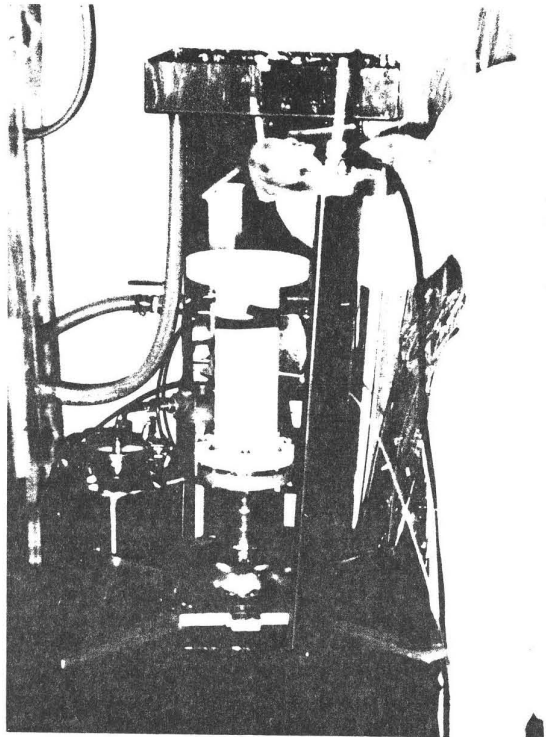


Fig. 4. A successfully developed megasonic oscillator (insert type).

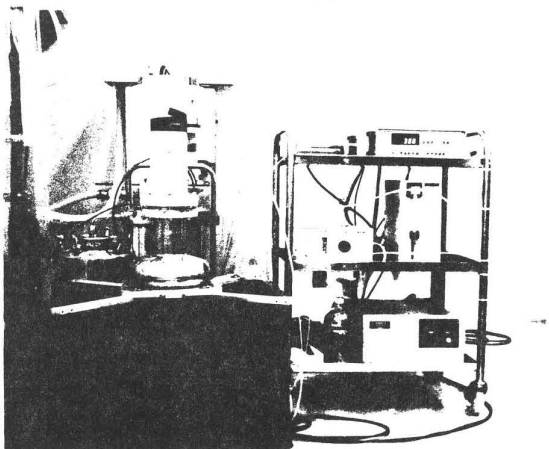


Fig. 5. View of the set up for megasonic rinsing with the insert type in the KEK class 10 clean room.

The experimental set up is shown in Fig.5.

Fig. 6 is a preliminary result on the rinsing time of MSR. In these experiments, MSR was turned off during the particle measurement. If no MSR, any particle reduction can not be seen in the outlet water, waiting even for two hours (mark;●). On the other hand after the 30 minutes MSR, particles were reduced to the half (mark; o). However, the tendency, which particles are reduced more, is not clear even waiting for 55 minutes. Taking MSR for more 16 minutes, a clear particle reduction with the overflow time was observed (mark; Δ). After overflowed for 50 minutes, almost of the particles thrown off from the surface by the megasonic agitation is floated away by the ultrapure water, so that the number of the particles at the outlet became close to the background level.

Fig.7 is a result on the overflow rate of the ultrapure water. In this experiment, MSR was turned on during the particle measurement. One notices a considerably high flow rate (> 2.3 l/min.) is required even for single cell cavities to get the enough particle reduction.

4. What water quality needs for the rinsing.

1) Just "filtered pure water" is enough for HPR.

So far we have said nothing about the water quality of the HPR. however, just deionized and 0.2 μm filtered pure water is enough for HPR. The water quality for HPR had been evaluated by cavity measurements. We did not see any large difference in the cavity performance with "0.2 μm filtered pure water" instead of ultrapure water. In the table 1 we compare the qualities of our ultrapure water and filtered/non filtered pure water.

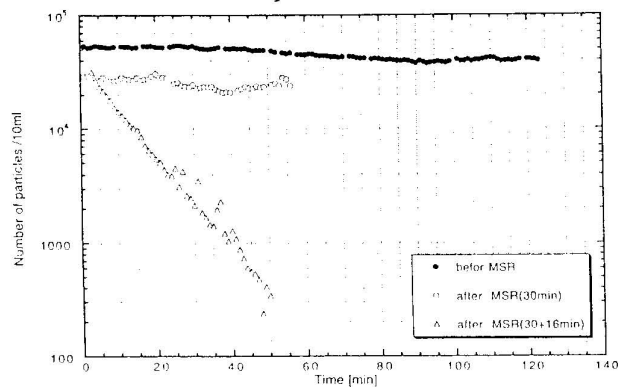


Fig. 6. Excellent particle reduction in the overflowed water.

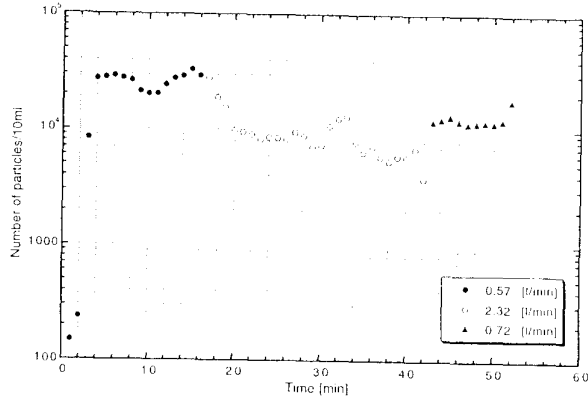


Fig. 7. Water flow rate dependence with particle reduction.

2) Usable pure water instead of ultrapure water ?

By the combination of HPR (0.2 μm filtered pure water) and the final light shower rinsing with ultrapure water, we have repeatedly the good cavity performance ; $Q_0 = 1 \times 10^{10}$, $E_{acc} > 28 \text{ MV/m}$. Here, one question comes out, whether the filtered pure water is usable for the final light shower rinsing or not. If yes, pure water is enough for the cavity rinsing.

To evaluate the quality of the water for the shower rinsing, we tried the following four kinds of water to two cavities (C-1 and C-2), and compared the cavity performance.

- 1) HPR[0.2 μm filtered pure water] + shower rinsing [ultrapure water] ; as reference
- 2) HPR[same as 1)] + shower rinsing [non filtered pure water]
- 3) HPR[same as 1)] + shower rinsing [0.22 μm filtered pure water]
- 4) HPR[same as 1)] + shower rinsing [0.10 μm filtered pure water]

The results are presented in Fig. 8. In this figure, the referenced Q_0 - E_{acc} curve is the mark; \bullet , with the C-1 cavity. The result of 2) is

Table 1. Quality of our ultrapure / pure water

Analyzed Items / Sampling Date	Ultrapure water			Pure water		
	'87 7/21 at Use point	'88 2/18 at Use point	'95 7/27 at Use point	'94 10/21 at HPR inlet (without filter)	'95 7/27 at Use point (without filter)	'94 10/21 at HPR outlet (with 0.2 μm filter)
Particles(> 0.2 μm) [pieces/ml]	16	19	30	899	219	134
Bacteria [pieces/ml]	2.7	0	0	1 - 7	4 - 8	4 - 29
SiO ₂ [ppb]	12	25	-	-	-	-
TOC [ppb]	180	< 50	270	80	260	180
Resistivity [M Ω -cm]	17.6	17.6	17.6	6.8 - 8.0	8.3	6.8 - 8.0

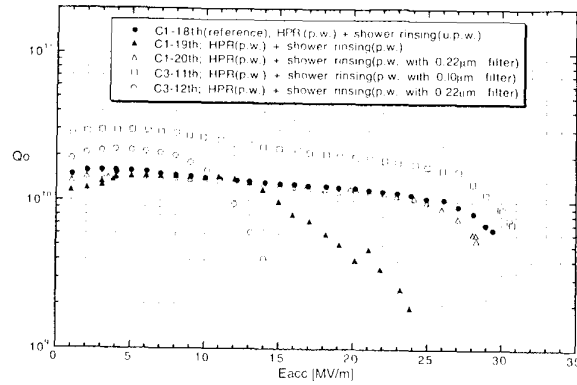


Fig. 8. Cavity performance by pure water rinsing.

shown by the mark; \blacktriangle . One can see the heavy field emission from 13 MV/m. As seen in Table 1, it would be due to the particles in the pure water. On the experiment 3), we had tested two cavities with the C-1 and C-3 cavity. For the C-1 cavity, the performance similar to the reference was obtained finally, though the processing levels appeared at 15 - 20 MV/m (mark; Δ). However, the heavy field emission appeared on the C-3 cavity (mark; \circ). We have not yet understood whether the large difference is due to the rinsing itself or not. The filter was reused. Though it was wet any care was not taken about keeping, so that bacteria would propagate in the filter. We have to test on not only the filter mesh size but also bacteria contamination more carefully.

On the experiment 4), we obtained a good result with the C-3 cavity as shown the mark; \square . In this case, any processing level did not appeared. Now we are doing the same experiment using the C-1 cavity to see the reproducibility. Though the result still has a poor reproducibility, there is a large probability to use the filtered pure water for whole cavity rinsing. If succeed in it, it brings a large cost reduction on the cavity treatment.

for cavity rinsing.

5. Multipacting in round shaped cavities

The processing levels of the C-3 cavity in the experiment 3) are not sure whether it is related to the quality of water itself or not. We often see the processing levels at 15 - 20 MV/m in the cavities rinsed with ultrapure water. See Fig.9. On the TRISTAN 508 MHz cavities, the same processing levels were experienced at the field gradients of 7 - 9 MV/m.

On the appearance of the two side multipacting in the round shaped cavities, Dr. W. Weingarten has already reported with the CERN 500 MHz and 350 MHz cavities[5]. He assigned the level at 5.5 MV/m as the first order. Multipacting levels are linearly scaled by the resonance frequency of the cavities, if they have the similar shape. If scaled his value to 508 MHz, one expects the multipacting around 8 MV/m for the TRISTAN cavities, and for 1.3 GHz around 20 MV/m. Considering the difference in the cavity shape, these expected multipacting levels agree well with our processing levels. When the field comes close to the processing region, small oscillation is observed in the output power from the pickup port. From these consideration, we believe the multipacting is occurring in the processing levels. To see the shape effect on the multipacting, we fabricated three kinds of cavity with the CEBAF elliptical shape, Asymmetric shape (elliptical + spherical) and KEK spherical shape. The degree of the processing depends on the cavity shape, and it seems to be serious in the following order;

no proc.< spherical.< asymmetric.< elliptical.

The multipacting is usually easily processed out, but sometimes leads to quench. Multipacting appears often, but is not seen occasionally on the same cavity as to the spherical shape. So we guess there is still something not to be controlled in our procedure of surface treatment or vacuum evacuation. Several candidates are picked up; TOC (total organic carbon) in the water, carbon contamination during evacuation etc. We had never cared about TOC in the rinsing water so that our water has higher TOC level as seen in Table 1. We have used the rotary pump and turbo-molecular pump, then ion pump for evacuation of cavities. Oil from rotary pump has already contaminated our whole the evacuation system because we smell the oil after disassembly. We are eliminating the particle contamination by HPR, however, we might have to more take care about the other contamination like carbon in order to make

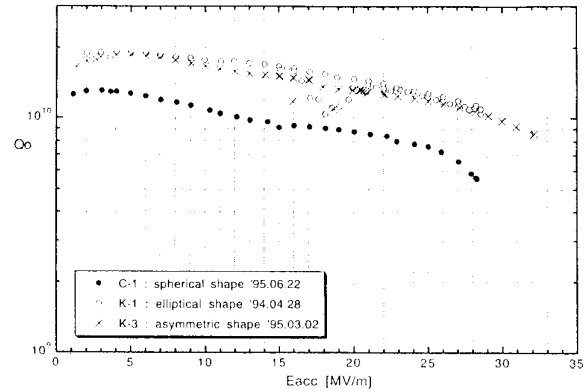


Fig.9 Processing levels observed at 15 - 20 MV/m in L-band KEK cavities.

completely field emission / multipacting free surfaces.

6. Conclusion

We have made sure that HPR is very powerful to eliminate the surface contamination. However, we have still often observe multipacting at 15 - 20 MV/m or field emission at $E_{acc} > 25$ MV/m, even use of HPR. We can hope for MSR to suppress the field emission at the high field. We might have to more care the carbon like contamination to make multipacting free surface.

On the quality of rinsing water, there is a large possibility to change ultrapure water to the filtered pure water. If we succeed in it, it will bring to a large cost reduction on the surface treatment.

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