ANALYSIS OF HIGH PRESSURE RINSING CHACTERISTICS FOR SRF CAVITIES*

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Abstract

High pressure rinsing (HPR) treatment has been widely used in the SRF cavity fabrication. This well- known process helps remove effectively undesirable emission tips from the inner surface of cavities, which are responsible for a different level's multipaction and hellium quenching. Also, the HPR treatment can clean or polish the RF (Radio Frequency) surface, which is critically sensitive to an applied magnetic field, by removing contaminants such as an organic oil, a remnant metal debris and dirty etchants from the cavity surface. Consequently, the HPR treatment contributes to improve quality factor during the cavity operation both by decreasing various field emission sites and by removing defects from the cavity surface. In this paper, we performed HPR experiments by using a simplified cavity structure, intentionally painted with a pattern on the inner surface. Therefore, we report how the surface treatment by HPR was carried out visually as functions of the distance between a target to be cleaned and a nozzle, and a water pressure.

INTRODUCTION

The fabrication of a superconducting cavity requires diverse and complicated processings: a cavity part forming by using a pressing machine [1], a part welding by electron-beam welding [2], a chemical polishing the inner surface of a cavity [3], and a heat treatment by using a high-vacuum furnace [4]. High pressure rinsing by using a high purity water having the resistance of 18 MΩ is also very important processing in the cavity fabrication. A surface state of a superconducting cavity determines a final cavity performance because a superconductivity changes depending on the surface state. The superconductivity tends to disappear when a critical temperature or a critical magnetic field is induced in a superconductor, and various defects, if any, on the surface of a superconductor, will break the superconductivity by inducing a critical temperature or a critical magnetic field [5]. Thus, it is important to keep the surface of a superconductor clean state having defects as less as possible to achieve high performance. We fabricated a prototype high pressure rinsing machine to clean the inner surface of a cavity. And we performed cleaning experiments with a prototype HPR in order to check out its functionality. HPR experiments were carried out with a simplified structure resembling a real cavity in order to observe indirectly how water rinsing treatment was being performed inside the simulated structure. The results by HPR treatment will be discussed as a function of a treatment time and a water pressure.

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EXPERIMENTAL

Equipment Setup

The specifications of a prototype HPR equipment fabricated by rare isotope science project (RISP) are listed in Table 1. And a picture of the fabricated HPR machine is shown in Fig. 1. For a simplicity, we will notate a HPR machine (or a HPR tool) as HPR in followings unless we need to distinguish them, because "HPR" itself can signify the meaning of an equipment and the operation performed by HPR machine at the same time. We designed the prototype HPR that can load two types of cavities, a half-wave resonator (HWR) and a quarter-wave resonator (QWR). Another prototype HPR for a single spoke resonator (SSR) is planning to be fabricated. Two types of nozzles are applicable in HPR: 0.5 mm and 0.6 mm in diameter, respectively. The part of nozzle can be classified into three areas: a top, a middle, and a bottom. This is shown in Fig. 2. Each area of the nozzle has equally 6 holes and they are evenly distributed through the entire nozzle. As one can see in Fig. 2, the six sprays of water from the top area have a positive 45 angle and another six sprays from the bottom area have a negative 45 angle with regard to an imaginary horizontal plane consisted of the middle sprays. The pressure of water was measured near an exit from a pump (P@Pump) and near an entrance to the HPR (P@HPR). Table 2 and Table 3 show the results. Thus, the actual pressure of water sprays is less than the pressure measured at the entrance to the HPR (P@HPR). We used deionized water having the resistance of 18 MΩ to operate the HPR.

Table 1: Specifications of High Pressure Rinsing Machine

Items	Specification	Values	Unit
Dimension	W×L× H	1 × 1 × 3	M
Nozzle	Size, Diameter	0.5, 0.6	mm
	Number of Nozzle	6 × 3	EA
Pressure	Water Pressure	Up to 140	bar

Painting the Simplified Cavity Structure

In order to observe visually how HPR works inside an cavity, we simplified an actual niobium (Nb) cavity. We separated only outer-conductor made of oxygen free high conductivity copper (OFHC) form the cavity, and this is shown in Fig. 3. The surface of the simplified structure was

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Table 2: The HPR Parameters with 0.5 mm Nozzle

Pump Frequency	P@Pump	P@HPR
17 Hz	35 bar	5 bar
25 Hz	71 bar	25 bar
30 Hz	99 bar	50 bar
35 Hz	131 bar	80 bar
40 Hz	165 bar	100 bar
45 Hz	200 bar	120 bar
48 Hz	220 bar	140 bar

Table 3: The HPR Parameters with 0.6 mm Nozzle

Pump Frequency	P@Pump	P@HPR
17 Hz	24 bar	-
25 Hz	48bar	10 bar
30 Hz	69 bar	20 bar
35 Hz	93 bar	45 bar
40 Hz	111 bar	50 bar
45 Hz	143 bar	70 bar
48 Hz	158 bar	80 bar

Figure 1: Prototype HPR fabricated by RISP: front view of HPR (left), side view of picture of HPR (right).

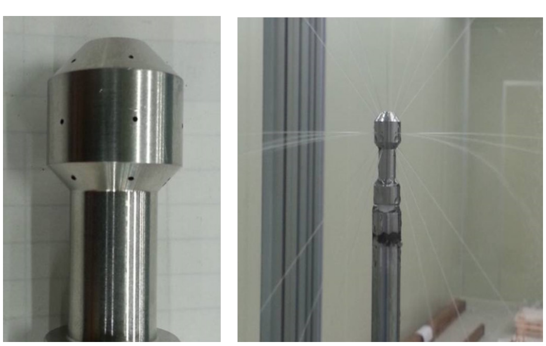

Figure 2: HPR Nozzle: nine holes on each top, middle, and bottom, angles of water sprays are 45 degrees.

specially treated in two ways. One is that we painted the surface with various painters to supply the worst condition on the surface. Water-soluble painters were promising such as a water-soluble painter or a crayon, because we needed to find out very proper painter that can be removed gradually to some extent with time under high pressure rinsing. This is shown in Fig. 4. The painted area was 100 × 150 mm^2. The other is that we artificially polished the surface of the simplified structure with a SiC (silicon carbide) sand paper of 100 grit to make the surface rough. Because we might observe that the HPR could decrease the surface roughness to some extent by polishing. The surface roughness was measured after HPR by a surface roughness tester (Surftest SJ-301, Mitutoyo).

Figure 3: Simplified structure for HPR experiment, outer-conductor is separated from the cavity: (a) Nb half-wave resonator, (b) simplified structure (outer-conductor made of OFHC) of the actual cavity, and (c) the inside view with no painting.

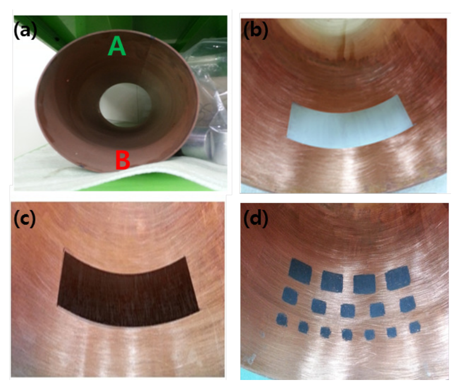

Figure 4: Various paintings on the simplified structure, painted area is 100 × 150 mm^2 : (a) A, B represents the part close to a nozzle as 30 mm and far from a nozzle as 170 mm, respectively, (b) inside view where painted by water-soluble board marker, (c) inside view where painted by permanent marker, and (d) inside view where painted with the pattern by water-soluble crayon.

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RESULTS

HPR experiments were performed with the 0.5 mm nozzle to produce high enough water pressure. We found the proper painter for HPR experiments, and it was the water-soluble crayon (see Fig. 4 (d)). Unfortunately, other painters were not successful. Some painters were removed almost instantly upon being exposed to the high pressure water regardless of the water pressure. For other painters, it was almost impossible to remove them within a reasonable HPR treatment time. The HPR results are shown in Fig. 5 and Fig. 6. Figure 5 shows the HPR results performed at 60 bar (P @ HPR, refer to Table 2) and Fig. 6 shows the results from 100 bar. The two top pictures in Fig. 5 and Fig. 6 show the painted surface with no HPR. In both figures, the left series of pictures followed by the vertical green arrows were taken from the part close to the HPR nozzle (part A in Fig. 4 (a), the distance between a nozzle and the target place was 30 mm). And the right pictures followed by the vertical red arrows were taken from the part far from the HPR nozzle (part B in Fig. 4 (a), the distance between a nozzle and target place was 170 mm). Each pass of HPR took around 15 min. with the 20 mm/min. moving speed of nozzle. First, we confirmed the prototype HPR worked successfully by removing painters from the surface of the experimental structure. And we observed that the close part to the nozzle was cleaned better than the part far from the nozzle. That is, the series of pictures followed by green arrows showed more cleanness than the right series of pictures. The cleanness improved as the pressure of water and the number of HPR treatments increased in all cases. The effects of the HPR on the roughness change as functions of the water pressure and the number of HPR treatments are listed Table 4. The mean roughness decreased slightly with the HPR treatments. And the amount of decrease was large in the case 100 bar of P@HPR. The roughness by 2 passes with the HPR at 100 bar of P@HPR already showed better the performance than that with the 3 passes of 60 bar of P@HPR.

Table 4: Mean Roughness Change of the Surface with the Number of HPR Passes and the Water Pressure

No. of Pass	P@HPR: 60 bar	P@HPR: 100 bar
0 pass	1.83 μm	1.83 μm
1 pass	1.77 μm	1.71 μm
2 passes	1.66 μm	1.62 μm
3 passes	1.65 μm	-

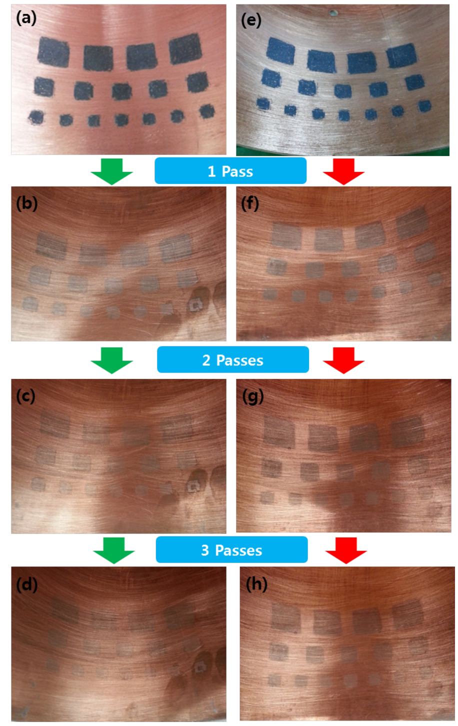

Figure 5: HPR Results with 60 bar of P@HPR: (a)-(d) show the surface states with the number HPR passes, the distance between a nozzle and a target is 30 mm, (e)-(h) show the surface states with the number HPR passes, the distance between a nozzle and a target is 170 mm.

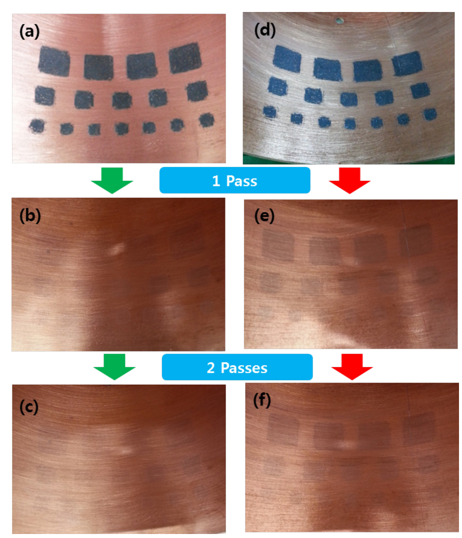

Figure 6: HPR Results with 60 bar of P@HPR: (a)-(c) show the surface states with the number HPR passes, the distance between a nozzle and a target is 30 mm, (d)-(f) show the surface states with the number HPR passes, the distance between a nozzle and a target is 170 mm.

DISCUSSION

We observed that the performance of the HPR was better with a target close to a nozzle from the Fig. 5 and Fig. 6. This is because an effective pressure of water exerted on the target becomes large when the distance between a nozzle and a target is small, while the effective pressure of water becomes small when the distance between a target and a nozzle is large. Similarly, we were able to observe that the performance of the HPR was better with 100 bar of P@HPR than 60 bar of P@HPR. One result to be discussed is that the performance of the HPR did not improve substantially when the distance between a nozzle and a target is large (see (e)-(h) in Fig. 5, and (d)-(f) in Fig.6. However, the performance of the HPR improved relatively substantially when the distance between a nozzle and a target is small. One possible explanation is that a critical pressure of water is needed to clean the surface effectively. Thus, it is important step to find proper pressure of the HPR for applying the prototype HPR to the actual niobium cavity. Regarding the surface roughness, we confirmed that the HPR improved (decreased) the surface roughness although the effect was not critical. However, by considering above preliminary data, we think that the HPR helps make the surface to be smoother more effectively depending on the surface states, and the pressure of the HPR. Therefore, we will need more successive experiments not only to find the optimized pressure for HPR, but also to confirm the effectiveness of the HPR on the surface roughness.

SUMMARY

We have performed the high pressure rinsing experiments by using a simplified cavity structure intentionally painted. By the visual inspection, we confirmed that HPR showed the better performance with the high pressure and the small distance from a nozzle to a target to be cleaned. The surface roughness of the simplified cavity structure improved with the number of the HPR treatments, in addition, the surface roughness improved with the high pressure.

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