ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-THPCAV002

LOW TEMPERATURE HEAT TREATMENT ON THE HWR CAVITY*

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Abstract

Institute for Basic Science have been constructing the superconducting LINAC, named RAON, composed of quarter-wave resonators (QWR) and half-wave resonators (HWR). All QWR cavities have been completely fabricated and successfully tested to be assembled in QWR cryomodules. For now, we have been testing HWR cavities over 50% of the total amount. For the testing period, a success rate experienced up and downs like we went through during the QWR tests. In many cases, we observed that some cavities did not reach requirement performance at 2K cryogenic temperature although they showed high performance at 4K. We increased the temperature of the heat treatment to cure the rapid Q drop at high gradient and observed most cavities passed the vertical tests after the heat treatment.

INTRODUCTION

Superconducting cavities have been tested to be installed in the low energy section of the linac, named RAON (it means 'delight' in Korean). This low energy section consists of two types of superconducting cavities, a quarter-wave resonator (QWR) and a half-wave resonator.

Total number of cryomodules needed for the low energy section are 22 of QWR cryomodules (1 QWR cavity per each cryomodule), 15 of type A HWR cryomodules (2 HWR cavities per each cryomodule), and 19 of type B HWR cryomodules (4 HWR cavities per each cryomodule). Thus, the total number of cavities to be installed for the low energy section are 22 QWRs and 106 HWRs, respectively.

All QWR cavities were fully tested and installed in the cryomodule last August, 2020. In the mean while, more than 50% of HWR cavities have been tested by the end of the 1st quarter of 2021 since the last August, 2020.

A domestic vendor (Vitzrotech Company) manufactured all HWR cavities and they performed a few critical surface treatment on the bare/jacketed cavities; chemical etching (BCP), high pressure rinsing, high temperature heat treatment [1] [2] [3] [4]. Typical conditions are summarized in Table 1. Surface-treated HWR cavities are delivered to IBS, and these cavities become ready to be tested by being carefully assembled through a vacuum system.

One of the important steps performed in IBS is "low temperature heat treatment on the cavity". It has been reported that the low temperature heat treatment not only saves the time needed for the RF cavity conditioning, but improves cavity performance at high electrical gradient by changing chemical compositions of the cavity surface. In this paper, vertical tests results of HWR cavities will be discussed, and furthermore, how cavity performance were cured by changing the heat treatment condition.

Table 1: Typical Surface Treatment for HWR Cavity

Surface Treatment	Values
BCP	HF:HNO_3:H_3PO_4=1:1:2
High Pressure Rinsing	Water pressure: 100 ~ 150 bar
High T. Heat treatment	650°C, 10 hrs
Low T. Heat treatment	Target temperature: 120°C

HEAT TREATMENT SETUP

A delivered cavity needs to be assembled/connected to vacuum system for the vertical test. Once the vacuum connection is over, cavities are heat-treated for 48 hrs in the test stand. Figure 1 shows the low temperature baking set up in the test stand.

During the baking, the cavity pressure remains under around 10^{-5} mbar, while the jacket is open at 1 atm. And because the cavity is connected to the jacket through only ports such as high pressure rinsing (HPR) ports and RF ports, the heat treatment is carried out mainly by a convection rather than conduction. Thus, the actual temperature of the cavities during the baking was not measured because it was difficult to directly measure the temperature of the outside/inside surface of the cavity.

The target temperature for low temperature baking in IBS was chosen 120°C because it has been reported that a cavity baked at this temperature shows good peformance. For this reason, the temperature of a heat controller is set 150°C by considering heat loss due to convection and surroundings for baking. The ramping speed of the controller is set 10°C/min. so that the cavity not to be contaminated by radical outgassing.

Q_0 with 150°C Setting

Vertical test results from two cavities are shown Fig. 2. Results were obtained from cavities of No.22 and No.38 out of 106 HWRs in total. In case of No. 22 HWR cavity, (a) of Fig. 2, it did not satisfy the requirement (2.3×10^9 at 6.6 MV/m of Eacc under 2K) at the 1st test. Similarly, No. 38 HWR cavity did not pass two times tests. Black and blue lines represent the results from the 1st test and 2nd test, respectively. For the 2nd test, another surface treatment

* This work was supported by the Rare Isotope Science Project of Institute for Basic Science funded by Ministry of Science and ICT and NRF of Korea 2013M7A1A1075764.
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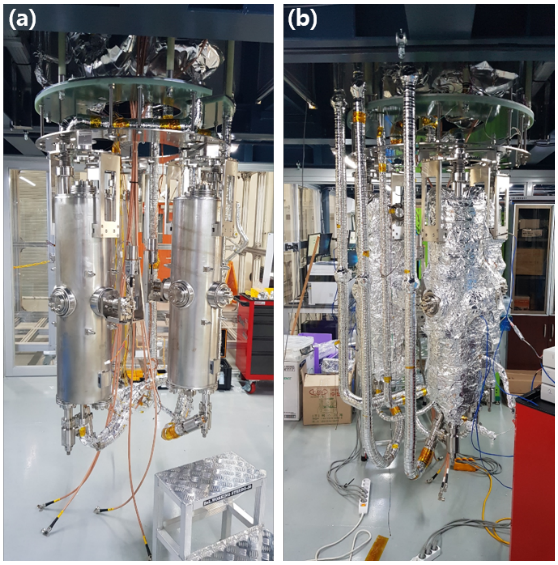

Figure 1: Low temperature baking setup for HWR cavities in test stand: (a) HWR cavities, (b) HWR cavities under heat treatment.

was performed: light BCP of 20 um, high pressure rinsing and one more low temperature heat treatment with a setting temperature as 150°C of the heat controller. Circle lines and square lines represents the results at 2K and 4K, respectively.

Figure 3 shows the 2nd test result of No. 22 HWR cavity. In this case, additional surface treatment and the additional low temperature heat treatment were same with the 1st test. The 2K results passed the test and the value was slightly larger than requirement. However, it was found that the Q graph of 2K (blue circle line) decreased rapidly than 4K Q (blue square line) and this phenomena was also shown in (b) Fig. 2.

Q_0 with 180°C Setting

In order to cure Q curves, we increased the setting temperature of the controller from 150°C to 180°C and it was applied to the 3rd test of No. 38 HWR cavity. Fig. 4 shows the 3rd test result of No. 38 HWR cavity. In this case, all additional surface treatment were exactly same as 1st and 2nd except that the temperature of the controller was increased from 150°C to 180°C.

Red circle/square lines represent 3rd tests. It was found that the Q curve of 2K was flattened dramatically at high gradient of Eacc after increasing the temperature. The measured quality factor at 2K was 9×10^9 at 6.6 MV/m of Eacc, which was more than 3 times larger than the requirement. This is in good agreement with previous studies regarding the effect of the low temperature heat treatment [5] [6]. It might be because the increased setting temperature made the actual temperature of the cavity surface close to 120°C although the actual temperature of the cavity was not measured. Thus, we believe that the low temperature heat treatment lowered the SEY(second electron yield) value effectively by changing the chemical composition of a niobium oxide surface [7].

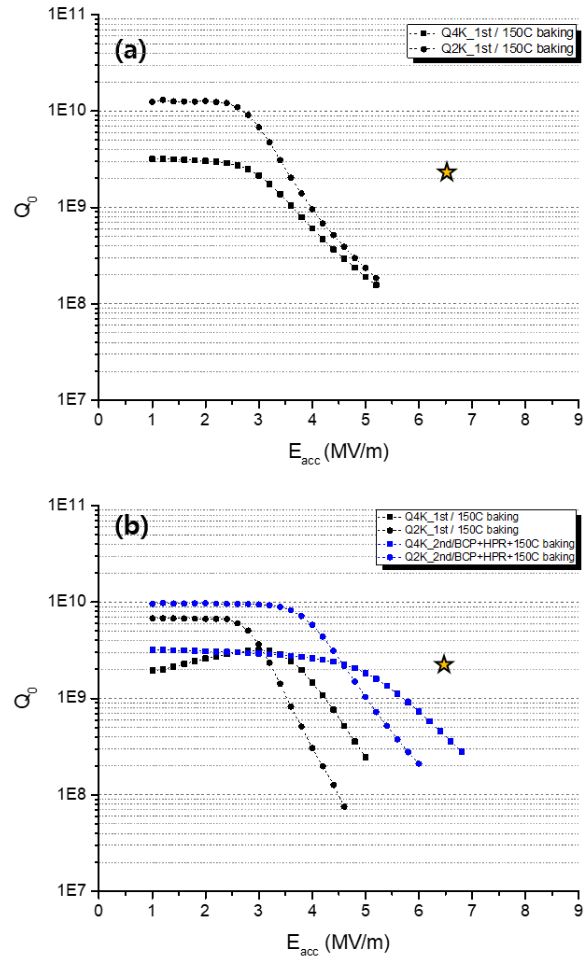

Figure 2: Vertical test results with 150°C setting: (a) Q_0 from the 1st test of No.22 HWR cavity (b) Q_0 from the 1st and the 2nd test of No.38 HWR cavity. The circle and the square represent Q_0 from 2K and 4K, respectively. Black lines represent the 1st result and the blue lines represents 2nd result. The yellow star is the requirement of the cavity as 2.3×10^9 at 6.6 MV/m of Eacc.

Q_0 with Field Emission

During the vertical testing, we observed many cases that the field emission was one of the main factors determining if cavity can pass or not. Thus, re-surface treatment of the cavity became an important process in order to pass cavities by removing of field emission tips.

Quality factor vs Eacc with filed emission of all tests after applying re-surface treatment to failed cavities (2 tests for No.22 HWR cavity, 3 tests for No.38 HWR) are shown in Fig. 5 and Fig. 6. In case of 150°C setting, the intensity of field emission of cavities decreased while the Xray turn-on increased as more surface treatment were performed. Also, the intensity of Xray at high gradient of Eacc from 2K was slightly higher than that of 4K, which means Q_0 drops more rapidly at 2K than 4K. However, in case of 180°C setting heat treatment, the intensity of Xray at high gradient of Eacc from 2K was very similar with the case of 4K.

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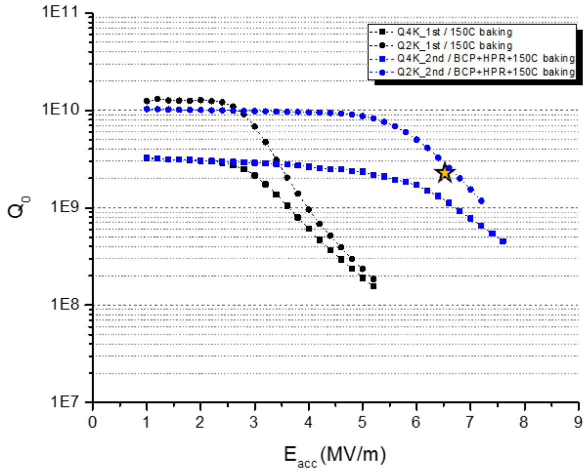

Figure 3: The 2nd vertical test results of No.22 after another surface treatment, the temperature of the controller was 150°C. The circle and the square represent Q_0 from 2K and 4K, respectively. Black lines and blue lines represent the 1st and 2nd test results, respectively. The yellow star is the requirement of the cavity as $2.3{\times}10^9$ at 6.6 MV/m of Eacc.

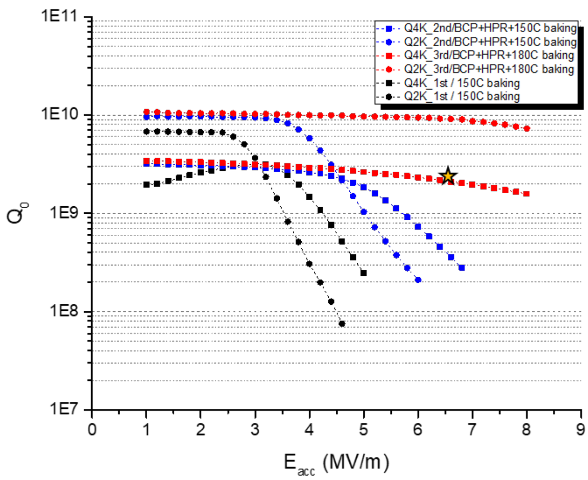

Figure 4: Vertical test results of No.38 HWR with 180°C setting. The circle and the square represent Q_0 from 2K and 4K, respectively. Black lines, blue lines and red lines represent the 1st, 2nd and 3rd test results, respectively. The yellow star is the requirement of the cavity as $2.3{\times}10^9$ at 6.6 MV/m of Eacc.

CONCLUSION

From the beginning of tests with No.1 HWR cavity, all cavities have been experienced low temperature heat treatment of 150°C setting of the heat controller. It was found that the cavity performance did not pass the test at 2K although the performance of the cavity at 4K looked promising. In order to cure cavities, we increased the the temperature of the heat controller to overcome the heat loss due to the convection and surroundings so that the actual temperature of cavities goes up to cure cavities effectively. With this,

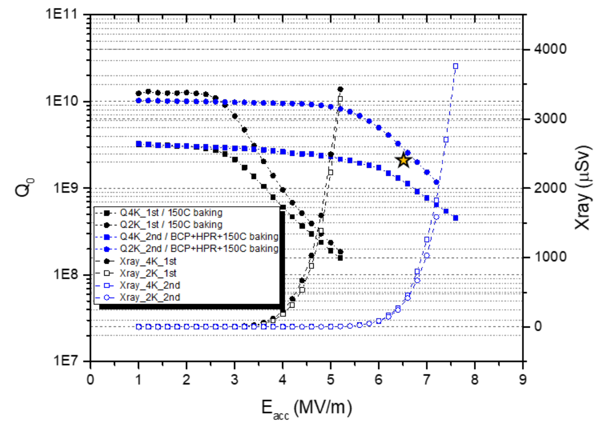

Figure 5: Xray field emission vs Eacc of No.22 HWR from 1st and 2nd test. Surface treatment conditions were exactly same except the temperature setting 150°C in low temperature heat treatment. The circle and the square represent Q_0 from 2K and 4K, respectively while the open circle/square represent the field emission from 2K and 4K, respectively. Black lines and blue lines represent the 1st and 2nd test results, respectively. The yellow star is the requirement of the cavity as $2.3{\times}10^9$ at 6.6 MV/m of Eacc.

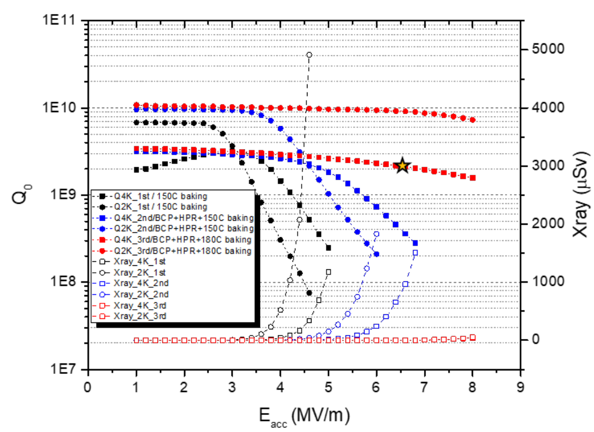

Figure 6: Xray field emission vs Eacc of No.38 HWR from 1st, 2nd, and 3rd test. Surface treatment conditions were exactly same except the temperature setting 150°C in low temperature heat treatment. The circle and the square represent Q_0 from 2K and 4K, respectively while the open circle/square represent the field emission from 2K and 4K, respectively. Black lines, blue lines and red lines represent the 1st, 2nd and 3rd test results, respectively. The yellow star is the requirement of the cavity as $2.3{\times}10^9$ at 6.6 MV/m of Eacc.

the performance of HWR cavities improved regarding the quality factor and the Xray field emission.

ACKNOWLEDGMENTS

This work was supported by the Rare Isotope Science Project of Institute for Basic Science funded by Ministry of Science and ICT and NRF of Korea 2013M7A1A1075764.

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