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HEAT TREATMENT FOR JACKETED HALF-WAVE RESONATOR CAVITY*

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Abstract

Vertical tests of a prototype half-wave resonator (HWR) cavity have been carried out in SRF test facility. Jacketed HWR (jHWR) cavity is tested both in the test pit and in the cryomodule, while bare HWR (bHWR) cavity is tested in the test pit. In a previous study, we reported that the heat treatment effect on the the cavity performance. Mainly, it was due to removing hydrogen gas which causes Q drop phenomenon during the heat treatment.

To improve the cavity performance, we baked the jacketed HWR cavity (jHWR) with the same heat treatment conditions as those for bHWR. We baked a jacketed HWR cavity (jHWR) for 10 hrs at 650°C under the partial pressure level of hydrogen as 10^{-5} Torr (partial pressure peak of hydrogen was 10^{-4} Torr) during the heat treatment. According to the results, the cavity performance improved as much as in the case of bHWR. In this study, we will report the heat treatment effect on the jHWR cavity performance with residual gas analysis (RGA) and the vertical test results.

INTRODUCTION

A superconducting cavity undergoes many fabrication steps from raw niobium to final product [1], [2]. Final cavities are classified as bare cavities and jacketed cavities. A bare cavity, which is as-produced, is covered by jacket (or called helium vessel) to confine 2K or 4K helium between jacket and outer surface of the cavity. Then, the jacketed cavity is integrated in the cryomodule, which is specially designed for supplying cryogenic environment to the cavity, by thermal insulation from the surroundings. A linear accelerator consists of many cryomodules that contain proper number of cavities according to the target energy. For the successful fabrication of LINAC, superconducting cavity, either as a bare cavity or a jacketed cavity, must be carefully tested. A quality factor Q_O from the cavity tests is one of the important parameters of the cavity along with an accelerating electric field gradient (E_{acc}).

During the cavity fabrication, the cavity must be treated with a mixed chemical solution, composed of nitric acid, phosphoric acid and fluoric acid, to remove a damaged surface of the cavity. This chemical polishing becomes the main process that makes hydrogen incorporated into the cavity. Hydrogen is well known as the main cause of Q disease, which means the quality factor of the cavity degrades due to hydrogen [3]. Hydrogens near the cavity surface agglomerate to form hydrides, and these hydrides increase the surface resistance of the cavity only to degrade the cavity performance. Heat treatment on the bare/jacketed cavity is very effective method to remove hydrogen gas from the cavity surface. Thus, cavity baking is useful way to recover the cavity performance after a long time chemical polishing.

In the previous study, we reported the baking effect on the bare half-wave resonator cavity (bHWR) with RGA and XRD analyses [4]. In this study, we baked the jacketed HWR cavity (jHWR) that has relatively low quality factor to improve cavity. The quality factor and the accelerating electric field are measured to check out the heat treatment effect with RGA results.

EXPERIMENTAL

Furnace Setup

Typical specifications of a vacuum furnace are summarized in Table 1. Figure 1 shows the picture of the furnace (left) and titanium box (right) in which jHWR cavity is loaded. Titanium box is for gathering outgassed hydrogen from the cavity because titanium has relatively lower vapor pressure than the niobium at 650°C baking temperature. The setup for the heat treatment in the furnace is shown in Fig. 2. As is shown in Fig. 2, cavity is loaded horizontally in the furnace. A bare HWR cavity (bHWR)and a jacketed HWR cavity connected with thermocouples for monitoring temperatures are shown in Fig. 2. In order to monitor the temperature of the cavity and the furnace, two thermocouple wires, made of platinum, are connected to titanium box, and two additional thermocouple wires are connected to jHWR cavity flanges. Not only to support the jHWR cavity mechanically during the heat treatment, but keep the cavity from being chemically reacted with SUS pillars of the bottom in the titanium box, alumina (Al_2O_3) frames are attached on top of SUS pillars [4].

The temperature for baking jHWR cavity is 650°C, and the ramping-up speed is 10°C per minute up to 650°C. The temperature profile is shown in Fig. 3. Heating time is 10 hrs under the chamber vacuum of about 10^{-5} Torr when the temperature reaches 650°C. The furnace is cooled down naturally after the baking, thus it usually takes 2 days to take out cavity from the furnace.

During the entire heat treatment including cavity cool-down, the partial pressures of all gases in the furnace chamber are monitored. The residual gas analysis detector (RGA, QME220, Pfeiffer Vacuum Co.) was used to monitor all outgassed impurities from the cavity.

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Table 1: Specifications of Vacuum Furnace

Items	Specification	Unit
Furnace size	1×1×3	Meter
Chamber vacuum	10^{-5} @ $650°C$, 10^{-8} @25 $°C$	Torr
Temperature	Operation at 650	Celsius

Figure 1: Vacuum furnace for the heat treatment in the SRF cleanroom: Cavity is loaded horizontally in the furnace with titanium box.

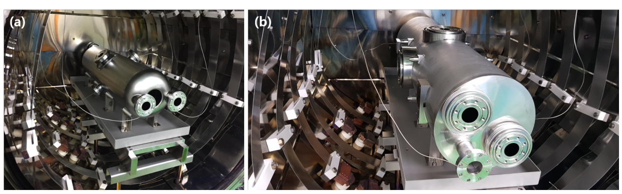

Figure 2: Horizontal loading of the jacketed and bare HWR cavity in the vacuum furnace: (a) bare HWR cavity and (b) jacketed HWR cavity.

RGA

RGA results from all gases in the furnace are shown in Fig. 3. Severe amount of hydrogen (red line) are outgassed - removed - from the cavity during the heat treatment. The maximum partial pressure of the hydrogen is 3×10^{-4} Torr. The maximum partial pressure of the hydrogen appears less than 2 hrs as 10^{-4} in order and gradually decreased during the heat treatment as 10^{-5} in order. Finally, the partial pressure of the hydrogen decreases to 10^{-8} in order after 2 days natural cooldown, which is same as background level in the furnace.

VERTICAL TEST

Figure 4 shows two types of places for the cavity test. Final jacketed cavities assembled with all auxiliary parts such as RF coupler, tuner, are integrated in the cryomodule ((a) of Fig. 4) and tested in the cryomodule, which is called a cryomodule test. Before the final cryomodule test of the cavity, either bare cavity or jacketed cavity must be tested in the test pit ((b) of Fig. 4), which is called a vertical test. This vertical test with bare/jacketed cavity is for checking out if the produced cavity can be installed in the cryomodule or not, thus, the vertical test is very important step not only to distinguish the functioning cavity from malfunctioning cavity, but save production time by avoiding inserting malfunction cavity into cryomodule. Since fixing the cryomodule requires a long time and the cost at the same time. The heat-treated jacketed HWR cavity in this study is tested in the vertical test pit in SRF test facility, which is shown in (b) of Fig. 4. Since the HWR cavity operates at 2K, the vertical test was carried out at 2K.

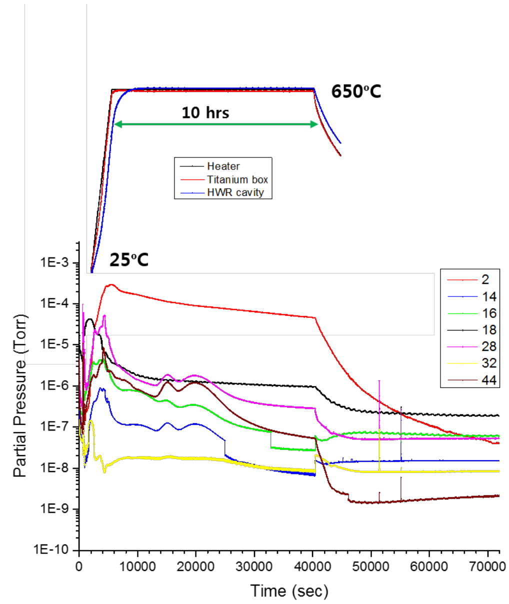

Figure 3: Temperature profile during the heat treatment (top) and RGA analysis (bottom): The maximum partial pressure peak of hydrogen (red line), 3×10^{-4} Torr, appears at around 2 hours.

Vertical test results of the jHWR cavity is shown in Fig. 5. In order to check out the heat treatment effect on the jHWR cavity, the performance of the cavity with no heat-treatment is also shown Fig. 5. The Q_O (quality factor at the low RF field) was improved by around one order magnitude. One of the possible reasons, this is due to hydrogen degassing, known as a major element causing Q drop (Q-disease). The number of hydrides formed on the surface upon cooling down to cryogenic temperature, decreases because the amount of hydrogen substantially lowered by the heat treatment. The accelerating electric field of the HWR cavity also increased up to 9 MV/m after heat treatment. This is because the surface resistance of the HWR cavity substantially decreased due to removing hydrides which act as scattering centers to increase the surface resistance. Thus, it is confirmed that the heat treatment improved the cavity performance by removing impurities, mainly hydrogen, from the cavity surface. Also, this result is in good agreement with the previous studies [4].

SUMMARY

The jacketed half-wave resonator cavity was baked for 10 hrs at 650°C. With RGA, it was confirmed that the substantial amount of hydrogen was effectively removed during the heat treatment. From the comparison of vertical test results before and after heat treatment on the cavity, we observed

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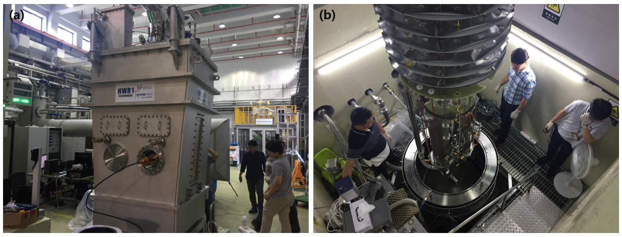

Figure 4: Cavity test: (a) cryomodule test in which the jacketed cavity is integrated with RF power coupler and tuner and (b) vertical pit test, in which bare or jacketed cavity is inserted with only variable coupler.

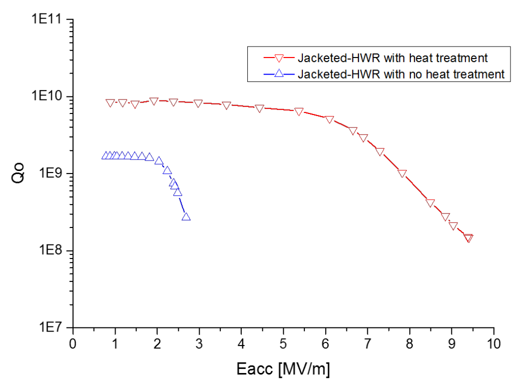

Figure 5: Quality factor (Q) vs. acceleration electric field gradient (E_{acc}) of the jacketed HWR cavity at 2K: A red reversed triangle line and a blue triangle line represents the heat treated HWR and no heat-treated HWR, respectively.

the quality factor improved by the heat treatment, due to the removing hydrogen that can form hydrides on the cavity surface during the cooling down. Also, the surface resistance of the cavity decreased by suppressing hydride formation, which in turn, shows the increased accelerating electric field gradient. However, we, RISP, still need to carry out a lot of cavity tests, including bare quarter-wave resonator (QWR) cavity, jacketed QWR cavity, and bare/jacketed single spoke resonator (SSR) cavity for the complete construction of LINAC. Additional test results and in-detail analyses will be studied during the cavity and cryomodule fabrication.

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