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Q DROP TENDENCY OF HALF-WAVE RESONATOR CAVITY*

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Abstract

Half-wave resonator superconducting cavities (HWRs) have been fabricated and tested. HWRs have been installed in the low energy section of the LINAC and being ready to be cooled down for the next step. All HWR cavities have been completely tested in two ways: vertical test and horizontal test. For the vetical test, HWRs were tested both at 4.2 K and 2.1 K cryogenic surroundings although the operating temperature is 2.1 K. Good cavity having higher quality factor than that of the target value showed the Q_0 drop tendency of 2.1 K was very similar to that of 4.2 K. However, in many cases, Q_0 drop tendency of 2.1 K was not similar with 4.2 K, rather Q_0 decreased more rapidly than 4.2 K which means the surface resistance of the cavity rapidly increased at 2 K surrounding. In this study, we will report that various Q_0 results of HWRs and discuss their Q_0 drop tendencies as a function of temperature, 2.1 K and 4.2 K along with field emission.

INTRODUCTION

One of factors determining the performance of the cavity is a quality factor, Q_0. The quality factor decreases as electric field increases due to the increase of the surface resistance. The surface resistance consists of temperature dependent term (R_{BCS}) and temperature independent term (R_{res}). The residual resistance, R_{res}, originates from the material itself such as a lattice structure, impurities and grain boundaries. On the contrary, the BCS resistance, R_{BCS}, coming from how much the material depends on the temperature, increases with temperature [1].

In addition to temperature effect on the cavity, a field emission, detected as x-ray radiation, is also a critical factor for limiting the cavity performance. Field emission current causes x-ray radiation known as Bremsstrahlung radiation [2]. With the existence of a proper field emission tip, the field emission current starts to flow at or above a specific electric field. Consequently, x-ray radiation starts to turn on at or above this electric field. The intensity of field emission current and the turn-on electric field depends on the size and the curvature of the tip. And the x-ray radiation increases as electric field increases similar to the field emission current.

At cryogenic temperature, a cavity must be conditioned with a proper range of the electric field in order to achieve the target applied electric field (E_{acc}) in the cavity. Technically, the cavity conditioning consists of two different purposes. One is "RF surface conditioning", which means cleans RF surface of the cavity to apply RF power effectively by removing the gases from the cavity surface such as H_2O and other gases. This process takes a few hours depending on the states of the cavity, and the low temperature baking is well known method to cut down conditioning time dramatically [3]. The other is "field emission conditioning", which means removes (lowers) field emission (x-ray radiation) with proper RF power. This conditioning process is to remove field emission tip itself or smoothen the tip. The RF power can be applied either as a pulse mode or a continuous mode depending on the intensity of x-ray radiation. This process must be carefully carried out at high gradient because a long time RF exposure to the cavity surface can degrade the cavity performance severely by damaging cavity surface such as creating craters, thus the RF mode and conditioning time must be carefully chosen in this case [2].

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VERTICAL TEST

Similar to a quarter wave resonator cavity (QWR) in RISP, HWR cavity showed a very similar Q_0 drop tendency, which means Q_0 decreased linearly with E_{acc} as long as no x-ray radiation observed, while Q_0 decreased dramatically after the onset of x-ray radiation. Figs. 1–3 show the typical three types of test results. For the HWR vertical test, the field emission conditioning was carried out in 2K while the RF surface conditioning was performed at 4K because HWR cavity operates at 2K and the RF power is more effectively applied at 2K due to the less surface resistance of the cavity.

RF Surface Conditioning

When the cavity reaches 4K, the input RF power is set 1 Watt and check out the pickup signal monitored through both a power meter and a spectrum analyser. The input RF power is controlled in order to increase the pickup signal of the cavity very slowly. This process ends when E_{acc} in the cavity reaches target E_{acc}, 6.6 MV/m, or a moderate amount of x-ray radiation begins, for example, 50 ~ 100 µSv/h in RISP test facility.

Field Emission Conditioning

The HWR cavity is cooled down to 2K cryogenic temperature for measuring quality factor. Increase input RF power CW/pulse mode to remove (lower) x-ray radiation while checking out E_{acc} of x-ray turn-on and the vacuum pressure in the cavity. It is good evidence to observe the change of x-ray turn-on and vacuum pressure because not only turn-on E_{acc} increases but the sharp vacuum peak appears when the field emission tip is removed or smoothened. Depending on the size and geometry of the field emission tip. The effect of

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field emission conditioning can be classified as three types. Fig. 1, Fig. 2, and Fig. 3 show three distinct types with the field emission conditioning. Fig. 1 shows the FE conditioning was successively performed, thus x-ray turn-on E_{acc} increased and x-ray radiation at the same E_{acc} decreased. On the contrary, Fig. 3 shows the FE conditioning deteriorated the cavity due to the long time RF exposure at high gradient, which means not only x-ray turn-on decreased but x-ray radiation increased at the same E_{acc}. As the last type, x-ray turn-on E_{acc} and the X-ray radiation slightly changed - slightly better or slightly worse - with FE conditioning, Fig. 2 shows that the cavity was slightly degraded with FE conditioning. Fig. 4, Fig. 5 and Fig. 6 show the turn-on E_{acc} when x-ray radiation starts with FE conditioning. X-ray radiation was replotted in log scale to determine E_{acc} more precisely.

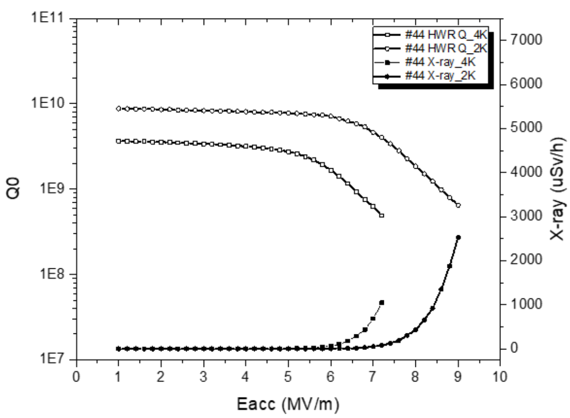

Figure 1: Quality factor and x-ray radiation of No.44 HWR: the square line and circle line represent 4K and 2K data, respectively.

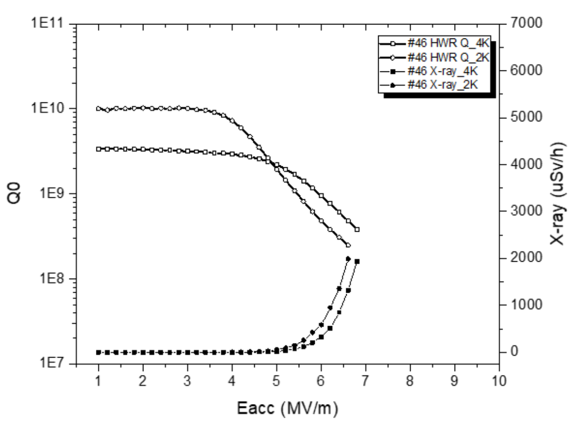

Figure 2: Quality factor and x-ray radiation of No.46 HWR: the square line and circle line represent 4K and 2K data, respectively.

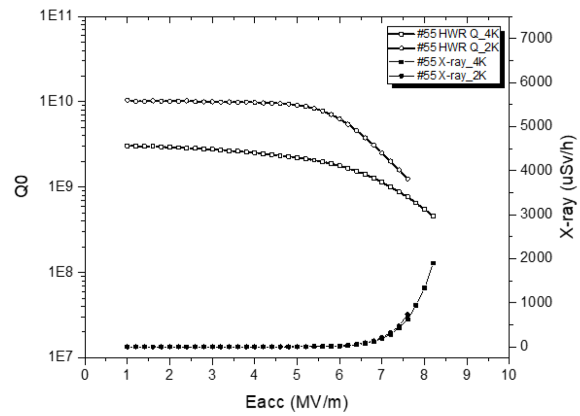

Figure 3: Quality factor and x-ray radiation of No.55 HWR: the square line and circle line represent 4K and 2K data, respectively.

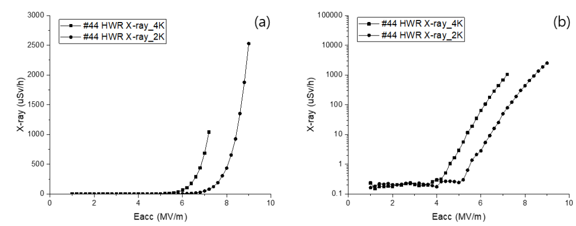

Figure 4: Turn-on E_{acc} of x-ray radiation of No.44 HWR: the square line and the circle line represent 4K and 2K x-ray radiation, respectively, (a) plotted in linear scale and (b) replotted in log scale.

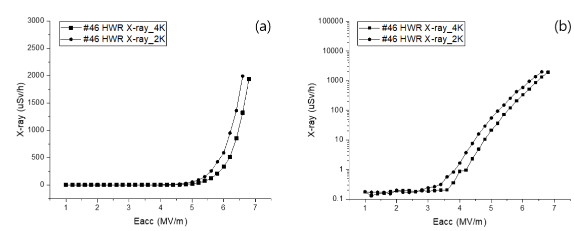

Figure 5: Turn-on E_{acc} of x-ray radiation of No.46 HWR: the square line and the circle line represent 4K and 2K x-ray radiation, respectively, (a) plotted in linear scale and (b) replotted in log scale.

ENHANCEMENT FACTOR, β

The enhancement factor accounts for explaining how field emission current changes depending on the geometry of the field emission tip. The enhancement factor, β was plotted from the x-ray radiation counting rate $\dot{N}$ (eq.1), which follows Fowler-Nordheim equation in the RF field, where E is the electric field at the surface, ϕ is the work function, γ represents the dependence of breamsstrahlung production and x-ray radiation absorption. The function v of the variable y=3.79×10$^{-4}E^{1/2}$ depend weakly on the electric field.

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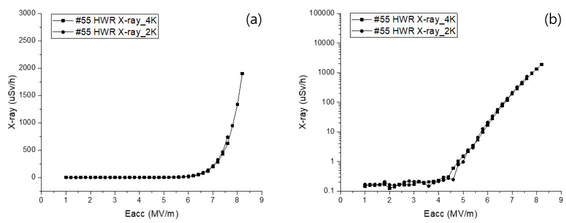

Figure 6: Turn-on E_{acc} of x-ray radiation of No.55 HWR: the square line and the circle line represent 4K and 2K x-ray radiation, respectively, (a) plotted in linear scale and (b) replotted in log scale.

In this relation, RF field change, the generation of the field emitted electrons, the acceleration of electrons, and the absorption of the x-ray radiation are taken into account [4]. The values of β calculated from the fitting of x-ray radiation are summarized in Table 1. The value of enhancement factor, β_{2K} compared with β_{4K}, shows the effect of FE conditioning at 2K on the cavity. In case of No. 44 HWR, the value of β_{2K} decreased with FE conditioning, thus x-ray radiation decreased (Q factor increased) and turn-on electric field, $E_{acc,2K,ON}$ increased. However, the FE conditioning did not make good effect on the No. 46 and 55. Rather, the FE conditioning deteriorated No. 46 due to the long time RF exposure at high gradient. Thus, all three typical types of FE conditioning effects on the cavity are shown in Fig. 7

$$\dot{N} = C(\beta E)^{5/2}(E^{1+\alpha})^{\gamma} \exp\left(\frac{-6.83 \times 10^{7} \nu(y)\phi^{3/2}}{\beta E}\right) \quad (1)$$

Table 1: Enhancement Factor and Turn-on E_{acc}

HWR	β_{4K}	β_{2K}	$E_{acc,4K,ON}$	$E_{acc,2K,ON}$
44	688	550	4.0 MV/m	5.2 MV/m
46	794	964	3.8 MV/m	3.2 MV/m
55	632	652	4.6 MV/m	4.5 MV/m

CONCLUSION

For the low energy LINAC segment, vertical tests of HWR cavities have been conducted for almost 2 years. We have observed that many cavities failed to pass the performance tests mainly due to the field emission, while a thermal quench also was another failure reason for tests. We have analysed why the quality factors of cavity at 2K showed different Q-drop tendency with FE conditioning. FE conditioning strongly depends on the initial state of the cavity surface, thus the effect of FE conditioning depends on the geometry of the field emission tip. FE conditioning is essential process for operating superconducting cavity, however FE conditioning must be carefully carried out not to deteriorate the cavity by controlling RF mode and conditioning time.

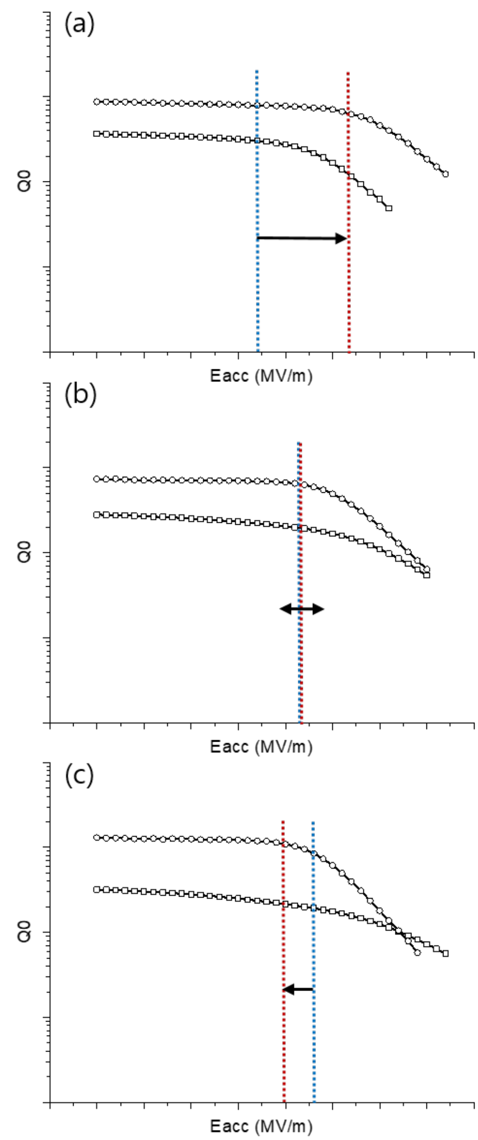

Figure 7: Three types of Q-drop tendencies with FE conditioning: (a)$\beta_{2K} < \beta_{4K}$, turn-on $E_{acc,ON}$ increased, (b) $\beta_{2K} \sim \beta_{4K}$, turn-on $E_{acc,ON}$ remains almost same, (c) $\beta_{2K} > \beta_{4K}$, turn-on $E_{acc,ON}$ decreased.

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