UNDERSTANDING Q SLOPE OF SUPERCONDUCTING CAVITY WITH MAGNETIC DEFECT AND FIELD EMISSION

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Abstract

RF test for quarter-wave resonator (QWR) and half-wave resonator (HWR) superconducting cavities is performed at low temperature. The quality factors of the superconducting cavities are measured as a function of accelerating electric field. The magnetic heating effect for the quarter-wave resonator (QWR) is studied. For the half-wave resonator (HWR) cavities, the Q slope degradation is investigated with x-ray radiation and field emission.

Magnetic heating and field emission

$$Q_o = \frac{2\pi f \mu \int |H(r)|^2 dV}{\int R_{Sur}|H(r)|^2 dS}$$: Quality factor is expressed with magnetic field

$$Q_o = \frac{G}{R_{Sur}}$$: Quality factor is expressed with surface resistance

$$R_{Sur} = R_{Res} + R_{BCS}$$: Surface resistance

$$P_{dis} = \frac{1}{2}\int R_S |H(r)|^2 dS$$: Dissipated power on cavity surface

$$R_{BCS} = \frac{C_1 f^2}{T}\exp(-\frac{\Delta}{k_B T})$$: BCS resistance comes from AC current

$$\Delta = \Delta_0 - \mathrm{MB_{peak}}$$: Band gap is reduced by magnetic defects

$$R_{Sur} = \frac{C_1 f^2}{T}\exp(-\frac{\Delta_0}{k_B T} + \frac{\mathrm{MB_{peak}}}{k_B T}) + R_{Res}$$: Surface resistance is expressed with magnetic moment and residual resistance

$$J = \frac{e\sqrt{E_F}F^2}{2\pi h(\Phi_W + E_F)\sqrt{\Phi_W}}e^{-4k\Phi_W^{1.5}/3F}$$: Field emission (FE) current density

$$I = \frac{Ae\sqrt{E_F}F^2\beta^2 \sin^2\omega t}{2\pi h(\Phi_W + E_F)\sqrt{\Phi_W}}e^{-4k\Phi_W^{1.5}/3F\beta \sin\omega t}$$: Field emission current for AC

$$\langle I \rangle = \frac{C_2 e\sqrt{E_F}F^{2.5}\beta^{2.5}}{h\sqrt{k}(\Phi_W + E_F)\Phi_W^{0.75}}e^{-4k\Phi_W^{1.5}/3F\beta}$$: Average FE current for AC

$$I_{X-ray} = I_0 + \frac{C_3\sqrt{E_F}F^{2.5}\beta_X^{2.5}}{(\Phi_W + E_F)\Phi_W^{0.75}}e^{-4k\Phi_W^{1.5}/3F\beta_X}$$: X-ray counting rate with x-ray field enhancement factor

Vertical test

Ref Figure 1: Pictures of the vertical test facility. (a) shows the overview of the vertical test site, (b) shows both the vertical test pit and the cryostat, (c) shows the solid state power amplifier (SSPA), (d) shows the control racks, (e) shows the personal safety interlock system (PSIS), and (f) shows the control panel for the PSIS.
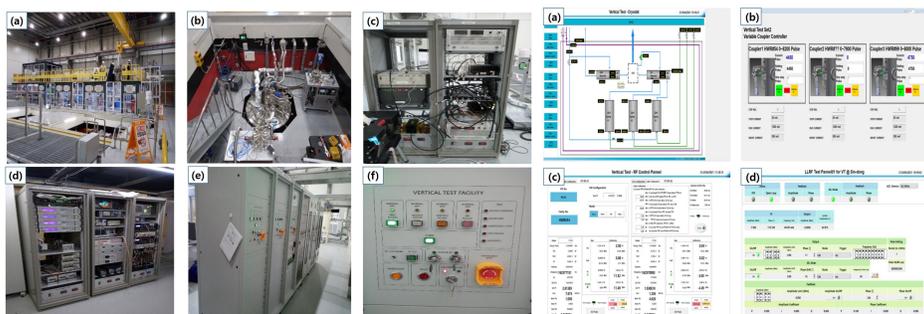
Ref Figure 2: Pictures of the human-machine interface (HMI). (a) shows the control panel of the cryostat, (b) shows the control panel of the variable couplers, and both (c) and (d) show the control panels of the low-level radio frequency (LLRF).

Figure 1: Q slope measurement as a function of accelerating electric field for the quarter-wave resonator (QWR) cavities at 4.2 K. This data shows the failed and passed QWR. The total number of QWR is 22 and all of them are passed. $[Q = 2.4 \times 10^8 \text{ at } E_{acc} = 6.1\,MV/m]$
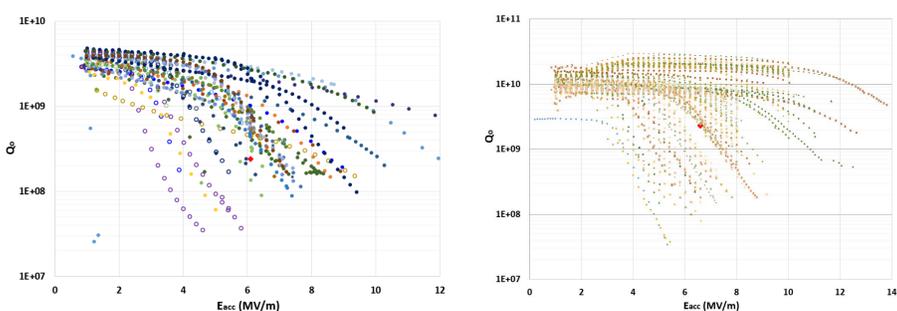

Figure 2: Q slope measurement as a function of accelerating electric field for the half-wave resonator (HWR) cavities at 2 K. This data shows the failed and passed HWR. The total number of HWR is 106 and all of them are passed. $[Q = 2.3 \times 10^9 \text{ at } E_{acc} = 6.6\,MV/m]$

Figure 3: Q slope measurement as a function of accelerating electric field for the quarter-wave resonator (QWR) cavities. The Q factor decreases as the accelerating electric field is increased.
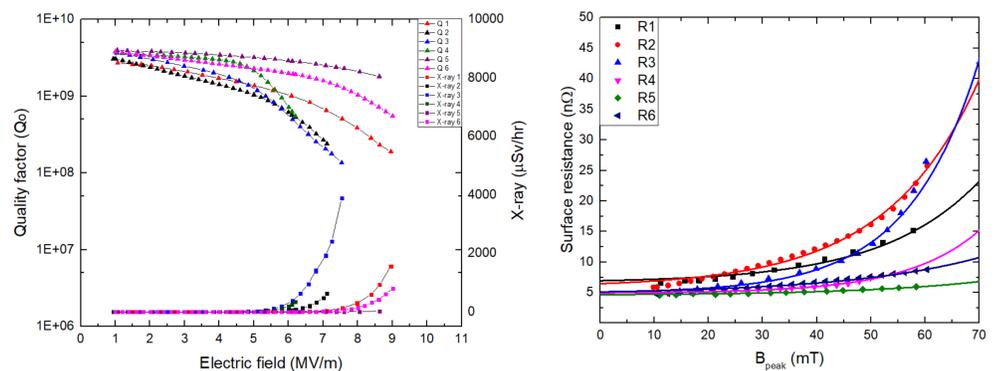

Figure 4: Magnetic heating effect of the surface resistances for quarter-wave resonator (QWR) cavities. The magnetic heating causes the quality factor decreases. The surface resistances for the QWR cavities are fitted with the magnetic heating equation. Magnetic moments for QWR 1, 2, 3, 4, 5 and 6 are as follows:

$$M = 3.3\times10^{-21}, 3.4\times10^{-21}, 4.4\times10^{-21}, 4.3\times10^{-21}, 2.5\times10^{-21}, \text{ and } 2.3\times10^{-21}[\text{J/T}].$$

Figure 5: Quality factors shown as a function of electric field for half-wave resonator (HWR) cavities. The quality factors are almost constant in the range of low accelerating electric field below 5 MV/m and decreases as the x ray radiation is increased in the range of the accelerating electric field above 5 MV/m.
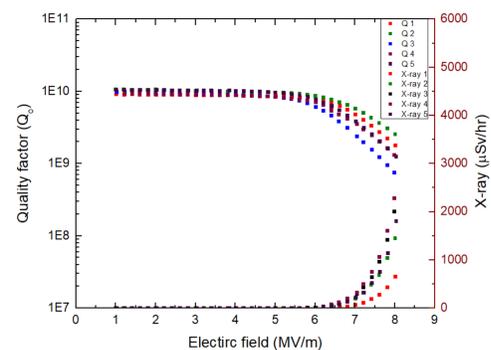

Figure 6: X-ray shown as a function of accelerating electric field for the half-wave resonator (HWR). The field emission increases as the accelerating electric field is increased. The x-ray is generated when the electrons emitted from the field emission and ionized gases are decelerated due to bremsstrahlung radiation. The x-ray increases as the accelerating electric field is increased.
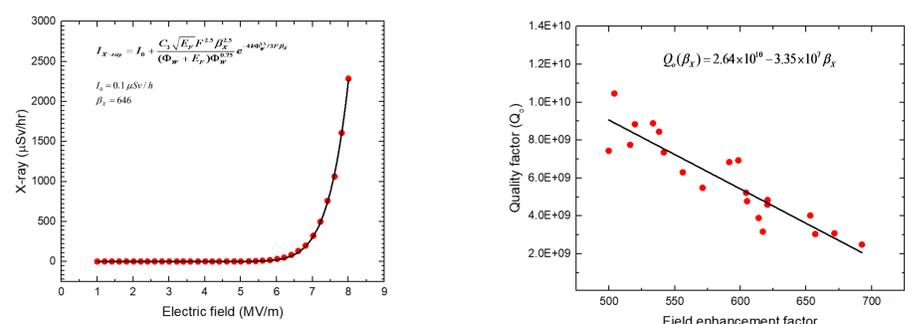

Figure 7: Quality factor of the half-wave resonators (HWRs) shown as a function of x-ray field enhancement factor. The quality factor for the half-wave resonators (HWRs) decreases linearly as the x-ray field enhancement factor is increased.

Summary

☐ Magnetic heating and field emission are introduced.

☐ Vertical test is performed for the QWRs and HWRs.

☐ Q slopes for the QWR and HWR cavities are measured.

☐ Magnetic heating effect for the QWR cavities is investigated.

☐ Field emission effect for the HWR cavities is studied.

☐ Quality factor of the HWR decreases linearly with the x-ray field enhancement factor.