Paper ID:

Analysis of Field Emission Effect on RAON Half-Wave Resonator (HWR) Superconducting Cavities

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Abstract

The field emission effect is a serious problem that degrades the performance of superconducting cavities. Metallic contaminants, surface curvature, and insufficient surface cleaning can cause electron emission from the cavity surface. Field emission typically occurs at the GeV-scale, but it can be also observed within the MeV-scale electric field of superconducting cavities. Metallic tip can locally enhance the electric field and field emission can be quantified as a field enhancement factor. In this research, the quality factor and X-ray date were obtained from a vertical test. Field enhancement factors were obtained by fitting the x-ray data using the Fowler-Nordheim tunneling current equation. A lower field enhancement factor indicates better field emission conditioning. As the field enhancement factor increases, the quality factor decreases.

Definition and Equation

$Q_0 = \frac{2\pi f \mu \int |H(r)|^2 dV}{\int R_s |H(r)|^2 dS}$: **Quality factor**

$Q_0 = \frac{G}{R_s}$: **Quality factor is expressed with surface resistance**

$R_s = R_{Res} + R_{BCS}$: **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**

$I_{FN}(E) = \frac{A_{FN} A_e (\beta_{FN} E)^{2.5}}{\phi}\exp(-\frac{B_{FN}\phi^{\frac{3}{2}}}{\beta_{FN} E})$: **Fowler-Nordheim tunneling current for AC**

Experimental setup for vertical test

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.

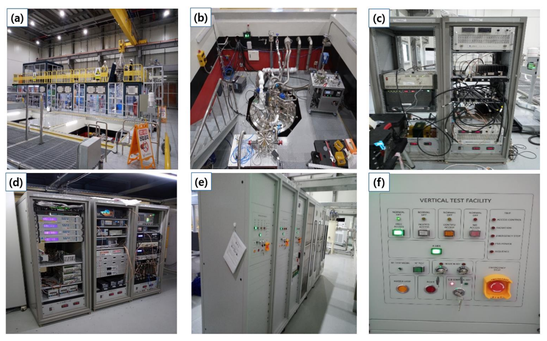

Figure. 1

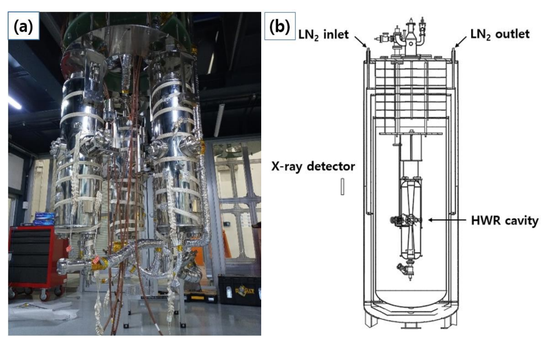

Figure. 2

Figure. 2: HWR cavities. (a) is the picture of the installed cavities on the top flange. Maximum 3 cavities can be tested. (b) shows the cryostat and there is a x-ray detector on the outside of the cryostat.

Test procedure and results

Quality factor and x-ray data were obtained at 4K environment. After 4K measurements, cool down to 2K, and RF conditioning was performed. RF conditioning at 2K is more efficient because it requires less input power than 4K environment. After RF conditioning, measurements for quality factor and x-ray were performed.

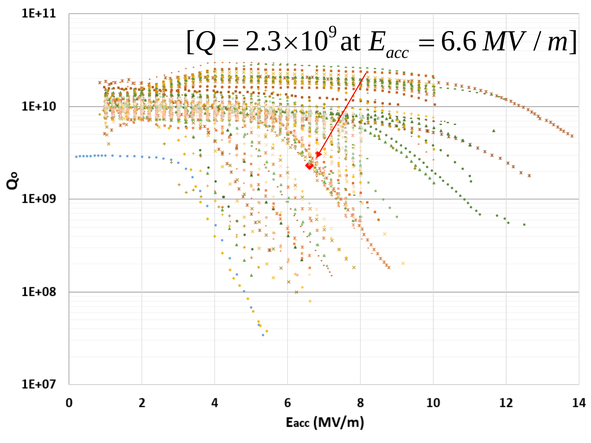

Figure. 3

Figure. 3: Quality factors were presented as a function of accelerating electric field for the half-wave resonator (HWR) cavities at 2K. This data shows the failed and passed HWR. If it failed to reach to target accelerating electric field and Q, surface treatment was performed and tested again. The total number of HWR is 106 and all of them are passed.

Conclusion

Figure. 4: Quality factors are shown as a function of accelerating electric field for HWR cavities. Before field emission occurs, decrease of quality factor is negligible. But as the x-ray radiation increases, quality factor decreases drastically.

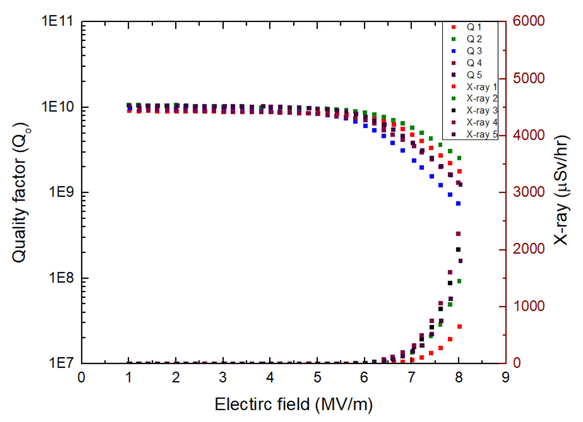

Figure. 4

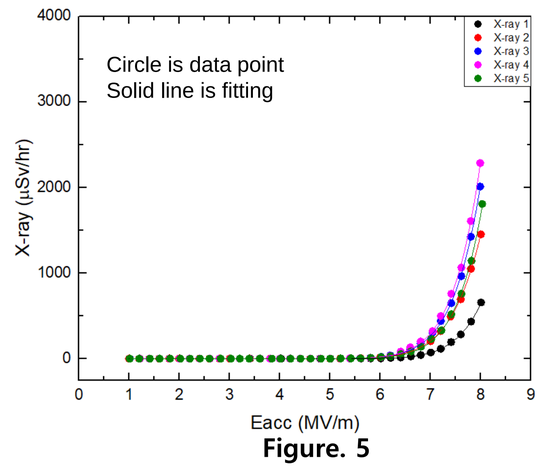

Figure. 5

Figure. 5: X-ray radiation data was fitted as a function of Fowler-Nordheim tunneling current equation. All of x-ray data was well fitted, because x-ray intensity is proportional to tunneling current. Field enhancement factors β_{FN} were obtained from fitting parameter. Each β_{FN} is 556, 654, 614, 621 and 571.

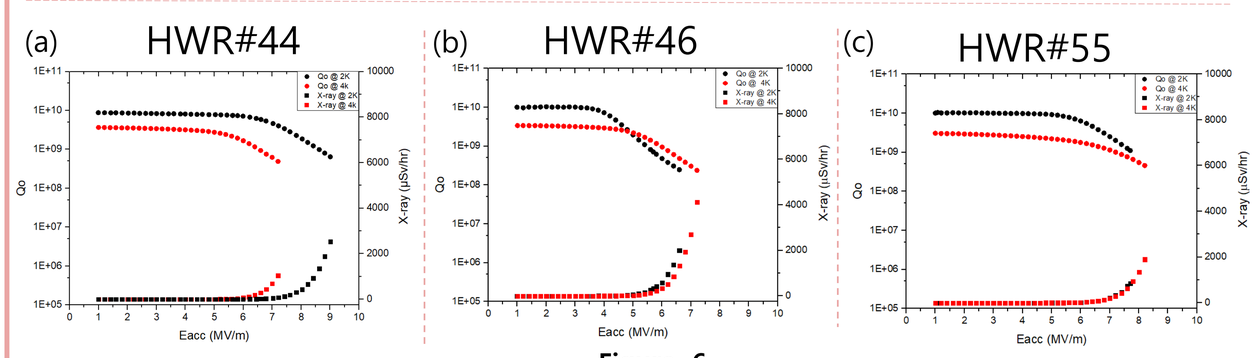

Figure. 6

Figure. 6: According to RF conditioning, all of 106 cavities are classified into 3 cases (a), (b), (c). (a) shows successful case. X-ray on-set increased but x-ray intensity decreased and quality factor was improved. β_{FN} changes from 688 to 550. (b) shows failed case. X-ray on-set decreased but x-ray intensity increased and quality factor was degraded. β_{FN} changes from 794 to 964. (c) shows unchanged case. X-ray intensity and on-set are almost same. HWR#44, 46, 55 represent each case, respectively. Field enhancement factor can indicate weather RF conditioning is successfully performed or not.

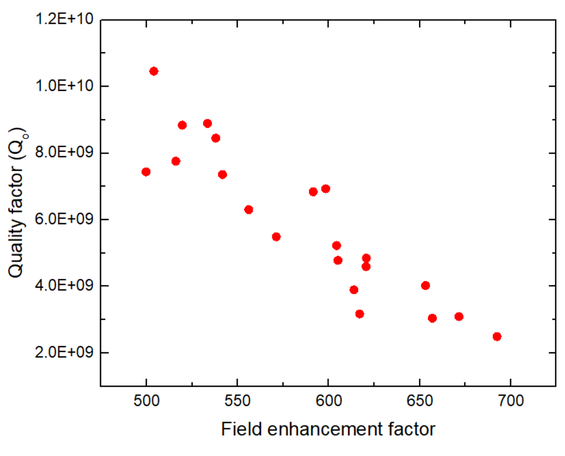

Figure. 7

Figure. 7: Quality factors at operation accelerating field (6.6MV/m) are shown as a function of field enhancement factor. The quality factor for the HWR decreases as the field enhancement factor increased. Since the contribution of field emission is dominant to quality factor, other effects(R_{res}, R_{BCS} etc…) are negligible at high accelerating field.

Summary

- Vertical test was performed, quality factors and x-ray were measured.
- X-ray intensity was fitted with Fowler-Nordheim tunneling current equation.
- Field enhancement factor indicate weather RF conditioning is successfully performed or not.
- Quality factor of the HWR decreases as the field enhancement factor increases.