Q₀ DEGRADATION OF LANL 700-MHZ $\beta=0.64$ ELLIPTICAL CAVITIES AND ANL 340 MHZ SPOKE CAVITIES*


Abstract
The quality factor (Q₀) of most of the six LANL $\beta=0.64$ 700-MHz 5-cell elliptical cavities starts to drop at $E_{acc} = 8 – 10$ MV/m, which may be related to multipacting. Residual resistances of these cavities were measured to be $5.0 – 7.6$ nΩ. The sensitivity of surface resistance to the external magnetic field was measured to be $0.22$ nΩ/mG. Q disease tests have shown no significant Q₀ degradation for both elliptical cavities and a spoke cavity with our 100 μm BCP.

1 INTRODUCTION
Obtaining and maintaining high Q₀ is important for superconducting (SC) RF cavities to reduce heat load to a cryogenic system, which will lead to a significant reduction of operation cost, e.g., from $3.5$ M to $2.0$ M/year at 2 K for accelerator production of tritium (APT) [1].

Six 700-MHz, $\beta=0.64$, 5-cell elliptical cavities were fabricated as prototypes for APT. Among them, five were made by industry and one was made at LANL. Most of them showed Q₀ drop at high fields together with X-ray emission.

In the region where electrons are not involved, Q₀ is determined by the surface resistance $R_s$, i.e., $Q_0 = G/R_s$, where G is the geometrical factor, a constant dependent on the cavity shape only.

2 Q₀ DROP AT HIGH FIELDS
Among the 6 cavities, 4 cavities showed steep Q₀ drop starting at an accelerating field of $E_{acc} = 8 – 10$ MV/m ($E_{peak} = 27 – 34$ MV/m, $H_{peak} = 557 – 696$ Oe). Figure 1 shows a typical Q – E curve. All the Q₀ drops were associated with X-ray emission, suggesting electron activity.

An asymmetric single-cell cavity (that consists of a half cell of the middle cell of an APT cavity and half of an end cell) was tested at Saclay and showed a similar result [6]. A multipacting (MP) calculation by Devanz showed a MP resonance zone at $E_{acc} = 4 – 8$ MV/m, although it could not reproduce the Q₀ drop at higher fields [6].

A comparative experimental study at Saclay with different cell shapes has shown that a cell shape with larger radius can achieve very high fields ($E_{acc} = 26$ MV/m) without MP. The MP calculation also did not indicate any MP bands for the cavities that were free of multipacting [6].

3 SURFACE RESISTANCE $R_s$
$R_s$ is expressed with two terms as,

$$R_s = R_{BCS} + R_{res},$$

where $R_{BCS}$ is the BCS surface resistance that depends on the cavity frequency $f$ and the surface temperature $T$ as follows.

$$R_{BCS} = A \cdot \left( \frac{f}{T} \right)^2 \cdot \exp \left( -\frac{\Delta}{k_B T_c} \cdot \frac{T}{T_c} \right),$$

where A is a constant, dependent on the material parameters of the superconductor, such as $\lambda_L$, $\xi_0$, mean free path ($l$), $2\Delta$ the energy gap and $k_B$ the Boltzman constant [2].

$R_{res}$ consists of two terms as follows.

$$R_{res} = R_{res} (H_{rf}) + R_{fl} (H_{rf}, H_{ext}, T),$$

where $H_{rf}$, $H_0$ and $H_{ext}$ are the RF magnetic field in the cavity, the residual resistance caused by trapped magnetic flux and the external magnetic field, respectively [7].

3.1 Experimental data on $R_s$
The constant A in Eq. (2), energy gap $2\Delta/k_B T_c$ and $R_{res}$ can be obtained by fitting a $R_s (=G/Q_0)$ versus 1/T curve with Eqs. (1) through (3).

Figure 2 shows an example that was obtained from an APT elliptical cavity named Sylvia.

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Figure 2: $R_s$ vs. $1/T$ curve of the Sylvia cavity. Shown at the top are the fitting results to get constants and $R_{\text{res}}$. Table 1 summarizes the parameters in the $R_{\text{BCS}}$ and $R_{\text{res}}$ of all the elliptical cavities and spoke cavities we have tested at LANL. The other data such as Q-E curves have been presented elsewhere [3, 4]. Also, some elliptical cavities have been tested at TJNAF at 2 K only and the temperature dependence data for those cavities are not available.

Table 1: Parameters of $R_{\text{BCS}}$ and $R_{\text{res}}$ of 700-MHz $\beta=0.64$ 5-cell elliptical cavities and ANL 340-MHz $\beta=0.29$ and 0.4 2-gap spoke cavities. The ANL $\beta=0.4$ cavity were tested twice, designated as (1) and (2).

$R_s = a*1/T^4 \exp(-b*1/T)+R_{\text{res}}$

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<th>Value</th>
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<td>$b$</td>
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<tr>
<td>$R$</td>
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Table 1: Parameters of $R_{\text{BCS}}$ and $R_{\text{res}}$ of 700-MHz $\beta=0.64$ 5-cell elliptical cavities and ANL 340-MHz $\beta=0.29$ and 0.4 2-gap spoke cavities. The ANL $\beta=0.4$ cavity were tested twice, designated as (1) and (2).
4.2 340 MHz Spoke cavities

Two dedicated $Q_0$-disease tests were performed with a 340-MHz $\beta=0.4$ 2-gap spoke cavity on loan from ANL. This cavity was chemically polished 98 $\mu$m with HF:HNO$_3$:H$_3$PO$_4=1:1:2$ by volume at 14 – 18 $^\circ$C. Figure 4 shows the cavity set on the insert. Figure 5 shows the time evolution of the temperature during the warm up to an intermediate temperature. Since around 100 K is reported to be the most dangerous temperature [9], we intended to hold the cavity at 100 K. As one can see in Fig. 5, however, the temperature increased up to 142 K after 86 hours due to lack of a temperature control mechanism, although the temperature was successfully kept at 100 – 102 K for 13 hours in the first test.

![Figure 4: ANL $\beta=0.4$ spoke cavity used for $Q_0$ degradation test.](image)

![Figure 5: Temperature evolution when the cavity was held at an intermediate temperature. Holding times for the first and second tests were 13 hours at 100 – 102 K and 86 hours at 100 – 142 K, respectively.](image)

The results at 4 K showed no degradation after up to 86 hours of holding the cavity at 100 – 142 K. The first data before warm up (solid triangle) showed lower $Q_0$ due to contamination from leaks, which was removed by RF processing as the power went up.

![Figure 6: $Q - E$ curves before and after the warm up to an intermediate temperature. No degradation was observed.](image)

5 ACKNOWLEDGEMENTS

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6 REFERENCES