Q_0 DEGRADATION OF LANL 700-MHZ β=0.64 ELLIPTICAL CAVITIES AND ANL 340 MHZ SPOKE CAVITIES*

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Abstract

The quality factor (Q_0) of most of the six LANL β=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 Q_0 degradation for both elliptical cavities and a spoke cavity with our 100 μm BCP.

1 INTRODUCTION

Obtaining and maintaining high Q_0 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, β=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 Q_0 drop at high fields together with X-ray emission.

In the region where electrons are not involved, Q_0 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 Q_0 DROP AT HIGH FIELDS

Among the 6 cavities, 4 cavities showed steep Q_0 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 Q_0 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 Q_0 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].

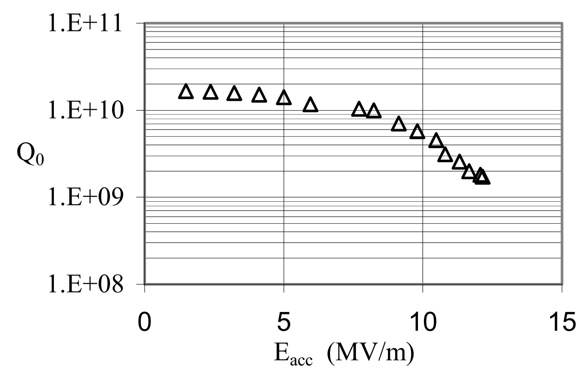

Figure 1: A typical Q – E curve for the APT elliptical cavity developed [3, 5]. E_{peak}/E_{acc} and H_{peak}/E_{acc} are 3.38 and 69.6 Oe/(MV/m), respectively. The limitation in field was field emission and available RF power.

To further investigate this issue, we are planning to test one of Saclay's MP-free cavities to confirm their results and identify the difference in the electron activities.

3 SURFACE RESISTANCE R_S

R_s is expressed with two terms as,

$$R_s = R_{BCS} + R_{res} \ , \quad (1)$$

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

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

where A is a constant, dependent on the material parameters of the superconductor, such as λ_L, ξ_0, mean free path (*l*), 2Δ the energy gap and k_B the Boltzman constant [2].

R_{res} consists of two terms as follows.

$$R_{res} = R_{res}(H_{rf}) + R_{fl}(H_{rf}, H_{ext}, T) \ , \quad (3)$$

where H_{rf}, R_{fl} 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 $2\Delta/k_BT_c$ 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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Rs = a*1/T*exp(-b*1/T)+Rres		
	Value	Error
a	3.9804e-05	4.4326e-06
b	18.734	0.35986
Rres	6.4452e-09	1.9664e-10
Chisq	1.5188e-17	NA
R	0.99857	NA

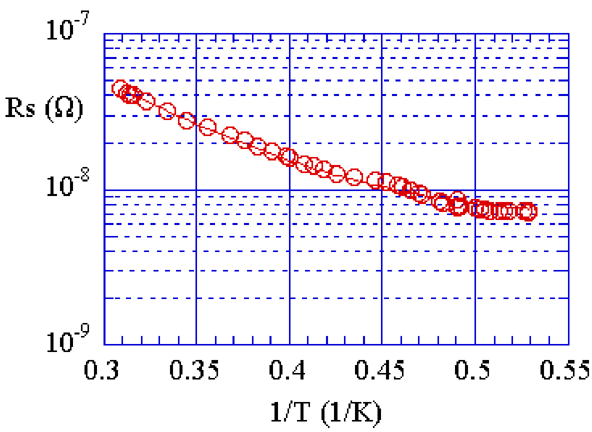

Figure 2: R_s vs. 1/T curve of the Sylvia cavity. Shown at the top are the fitting results to get constants and R_{res}.

Table 1 summarizes the parameters in the R_{BCS} and R_{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_{BCS} and R_{res} of 700-MHz β=0.64 5-cell elliptical cavities and ANL 340-MHz β=0.29 and 0.4 2-gap spoke cavities. The ANL β=0.4 cavity were tested twice, designated as (1) and (2).

Cavity	$A \cdot f^2$	$2\Delta/k_B T_c$	R_{res} [nΩ]
Elliptical			
AES	2.14E-05	3.49±0.08	4.99±0.72
Ayako	4.62E-05	4.17±0.13	7.55±0.73
Eleanore	3.36E-05	3.85±0.08	6.21±0.36
Sylvia	3.98E-05	4.07±0.08	6.45±0.20
ANL Spoke			
β = 0.29	1.73E-05	4.55±0.15	8.51±0.20
β = 0.40 (1)	4.48E-06	2.58±0.32	46.1±5.07
β = 0.40 (2)	1.84E-05	3.45±0.29	21.4±2.47

The ANL β=0.4 spoke cavity had many leak troubles at indium joints and may have been contaminated with particles and gases. Also, this cavity underwent excessive baking at >200 °C unintentionally. These may have caused much higher R_{res} than other cavities.

3.2 Effect of external magnetic field H_{ext}

We measured the H_{ext} in our cryostat with compensation coil on [5]. An average H_{ext} was ~5 mG. Figure 3 shows the dependence of R_s on the external magnetic field using the Sylvia cavity [5]. The sensitivity of R_s to H_{ext} was measured to be 0.22 nΩ/mG.

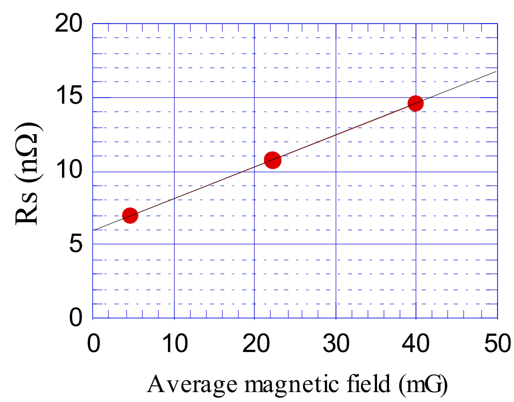

Figure 3: Residual resistance as a function of magnetic field averaged over 5 cells. The sensitivity is calculated to be 0.22 nΩ/mG.

4 Q_0 DISEASE TESTS

Since no cavities at LANL have been heat treated at >200 °C, whether Q_0 disease occurs after our buffered chemical polish (BCP) or not needs to be checked. Though we have not measured the absorbed hydrogen in the Nb used for our cavities, we have tested the effect of BCP.

4.1 700 MHz Elliptical cavities

Unfortunately, there was no funding for dedicated Q_0 disease tests for APT 5-cell elliptical cavities. However, two tests on APT single-cell cavities were carried out in 1997 [8].

In the first test a cavity that was chemically polished 100 μm with a solution of $HF:HNO_3:H_3PO_4$=2:2:3 by volume at <20 °C was held at 100 – 120 K for about an hour, and was then recooled to 2 K. R_s increased by 5 nΩ at 2 K compared to that before warm up, although R_s at 4 K after warm up looks lower than that before warm up in the R_s – T plot in Ref. [8]. In the second test with another cavity that was chemically polished 100 μm with the same solution, the cavity was held at 130 – 150 K for >2 hours. R_s increased by 10 nΩ. Since there is no R_s – T plot on this experiment in Ref. [8], the R_s at 4 K is unknown. This inconsistency at 4 K and 2 K should be addressed in the future. In any case, no significant Q_0 disease seems to occur after our 100 μm BCP.

4.2 340 MHz Spoke cavities

Two dedicated Q_0-disease tests were performed with a 340-MHz β=0.4 2-gap spoke cavity on loan from ANL. This cavity was chemically polished 98 µm with $HF:HNO_3:H_3PO_4$=1:1:2 by volume at 14 – 18 °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.

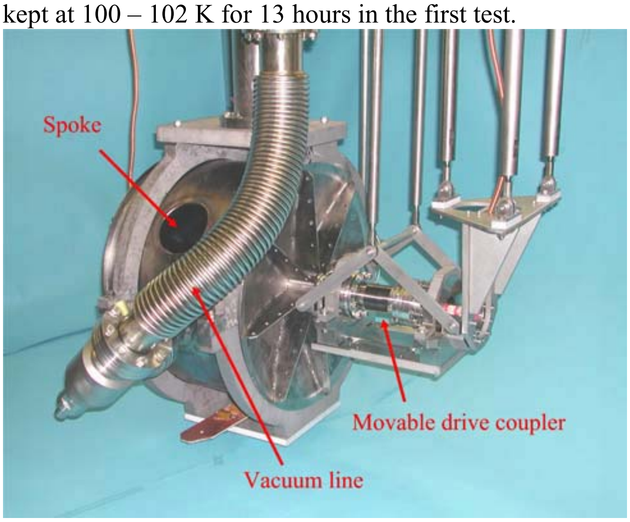

Figure 4: ANL β=0.4 spoke cavity used for Q_0 degradation test.

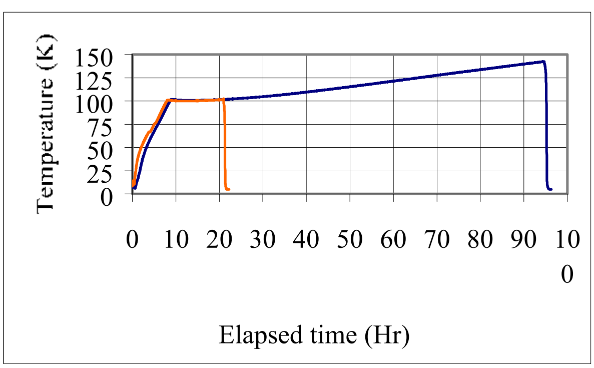

Figure 5: Temperature evolution when the cavity was held at an intermediate temperature. Holding times for the first and second tests were 13 hours at 100 – 102 K and 86 hours at 100 – 142 K, respectively.

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.

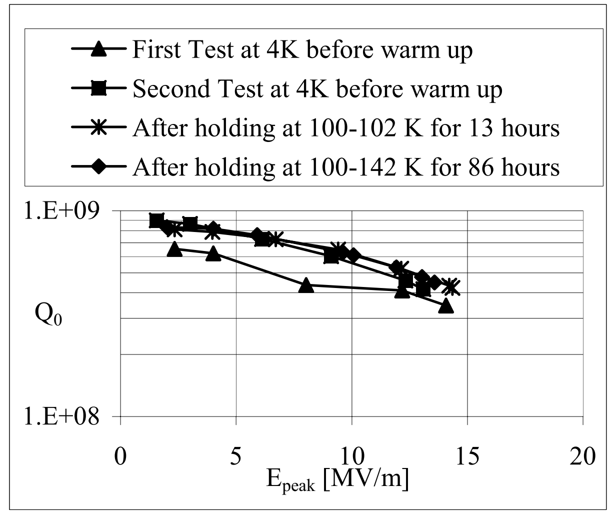

Figure 6: Q – E curves before and after the warm up to an intermediate temperature. No degradation was observed.

5 ACKNOWLEDGEMENTS

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