Probing the fundamental limit of niobium in high radiofrequency fields by dual mode excitation in superconducting radiofrequency cavities

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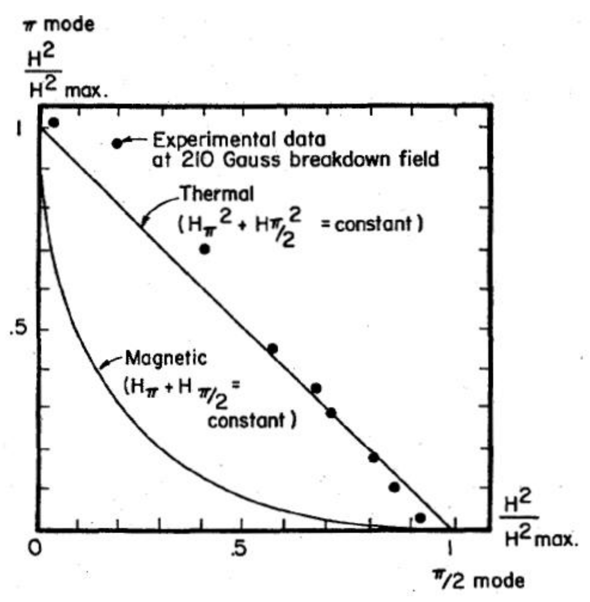
ABSTRACT: We have studied thermal breakdown in several multi-cell superconducting radiofrequency cavity by simultaneous excitation of two TM_{010} pass-band modes. Unlike measurements done in the past, which indicated a clear thermal nature of the breakdown, our measurements present a more complex picture with interplay of both thermal and magnetic effects. JLab LG-1 that we studied was limited at 40.5 MV/m in 8pi/9 mode, corresponding to B_{peak} = 173 mT in the end cells. Dual mode measurements of this quench indicate that this quench is not purely magnetic, and so we conclude that this field is not the fundamental limit in SRF cavities. With further advances in preparation techniques such as chemical polishing and centrifugal barrel polishing SRF cavities will reach higher gradients.

Introduction

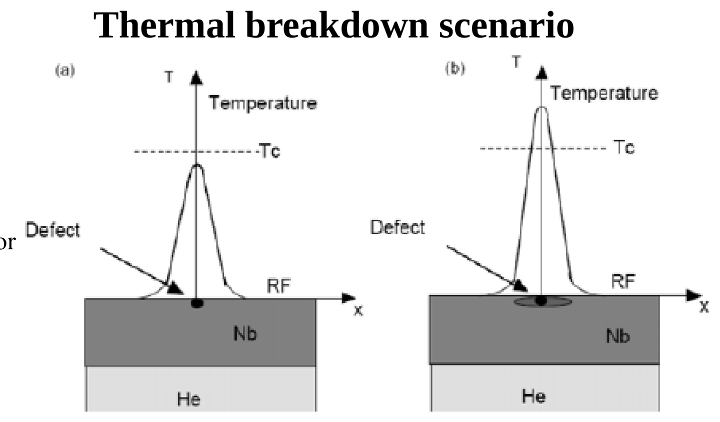
Multi-cell cavities have multiple pass-band modes. The surface field distribution in each cell is the same among all pass-bands, but relative field strengths between different cells vary from mode to mode. Hence, if two pass-band modes in a cell are excited at the same time their vector fields are collinear, however, the field strengths do not sum up coherently, because resonant frequencies vary among different pass-band modes.

In 1980 D. Proch exploited this fact to distinguish between thermal and magnetic breakdown in SRF cavities at that time. π and π /2 modes were excited simultaneously in several 2-cell cavities. By bringing cavities into repetitive quench with varying relative field strengths between two modes, quench dependence on mode mixture was measured (Fig to the right). The conclusion was -- "The data unambiguously supports the thermal model."



H. Padamsee, D. Proch, P. Kneisel, and J. Mioduszewski, IEEE Trans. Magn. 17, 947 (1981).

Thermal breakdown scenario

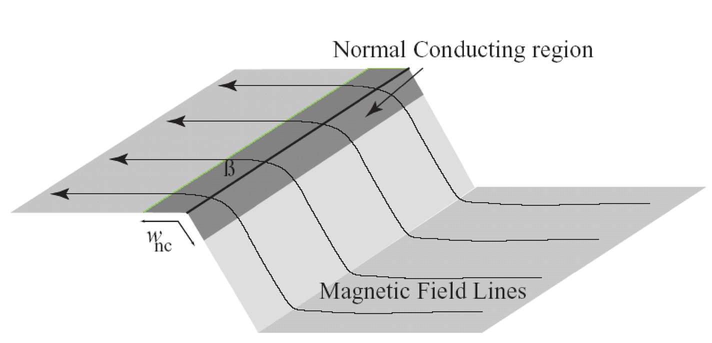


From H. Padamsee, J. Knobloch, T. Hays "RF Superconductivity for accelerators"

a)At low field, the temperature in the vicinity of the defect is higher than that in surrounding areas, but it remains below T_c.

b)As the field is raised, the temperature exceeds T_c, so that the niobium near the defect becomes normal conducting, and the power dissipation increases unstably.

Magnetic breakdown scenario

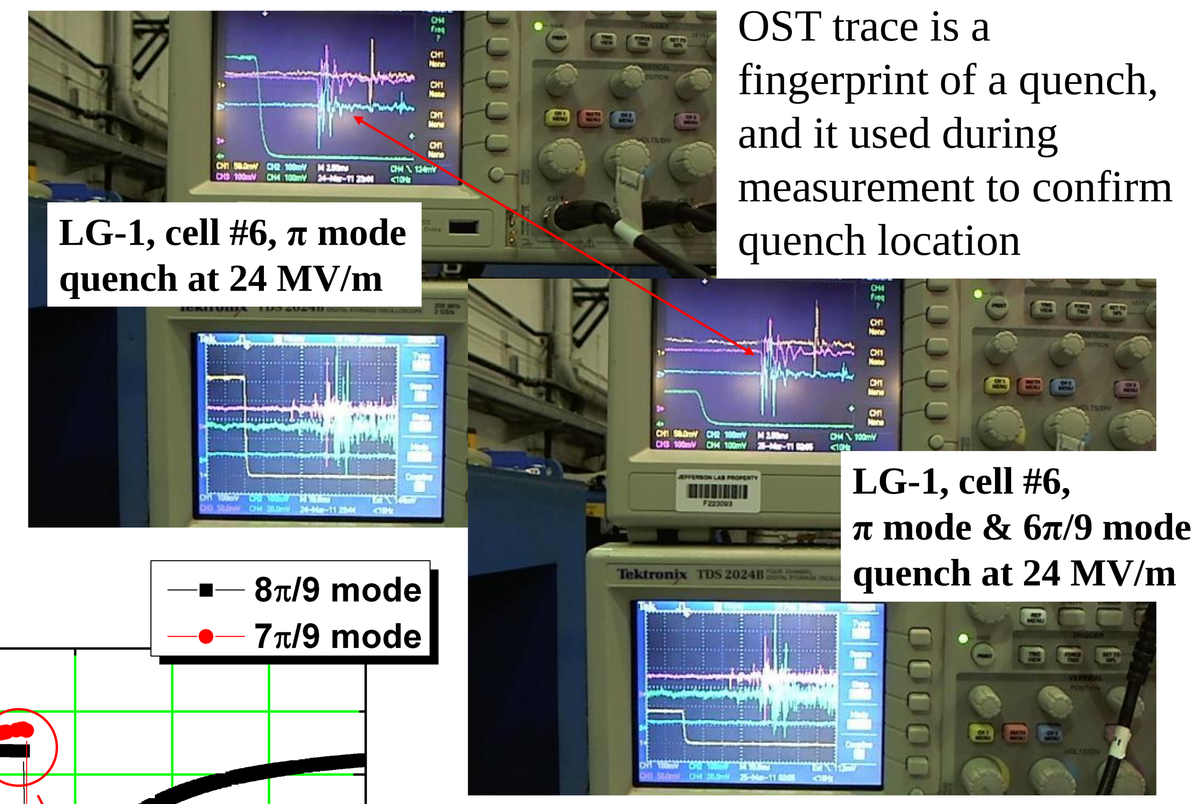


Geometrical enhancement , contamination, etc., creates a region with suppressed superconducting critical field, at field greater than H_c/β the region quenches and the power dissipation increases unstably.

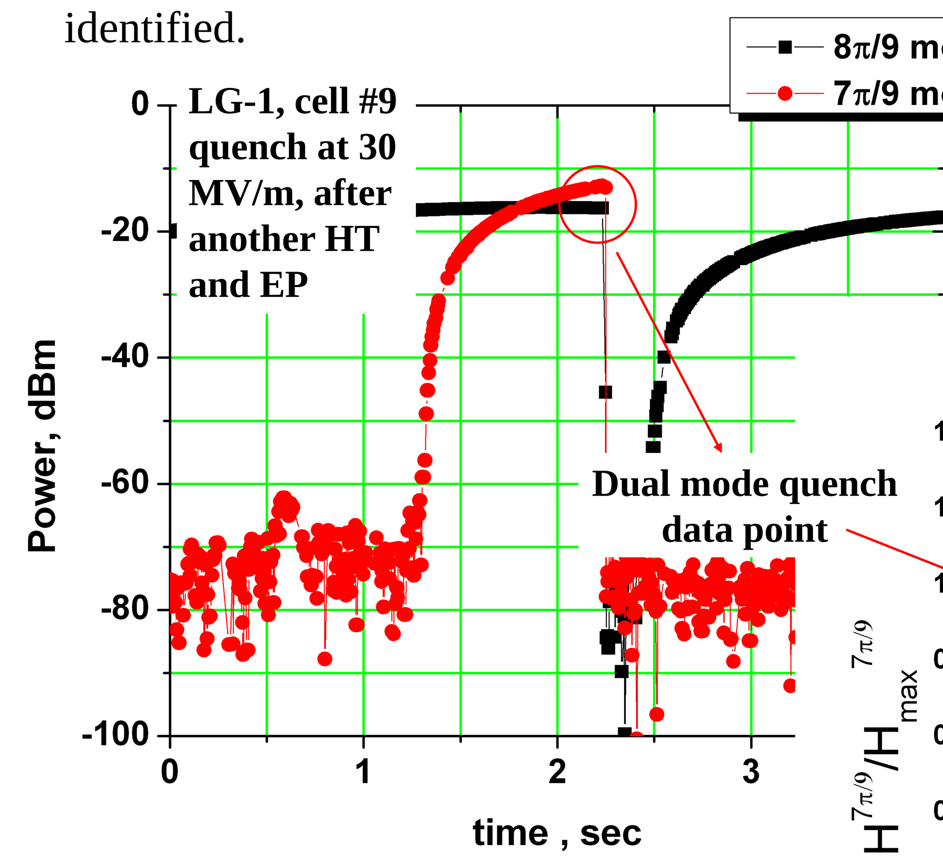
The picture from J. Knobloch , R. L. Geng, M. Liepe and H. Padamsee, "High-Field Q Slope in Superconducting Cavities Due to Magnetic. Field Enhancement at Grain Boundaries"

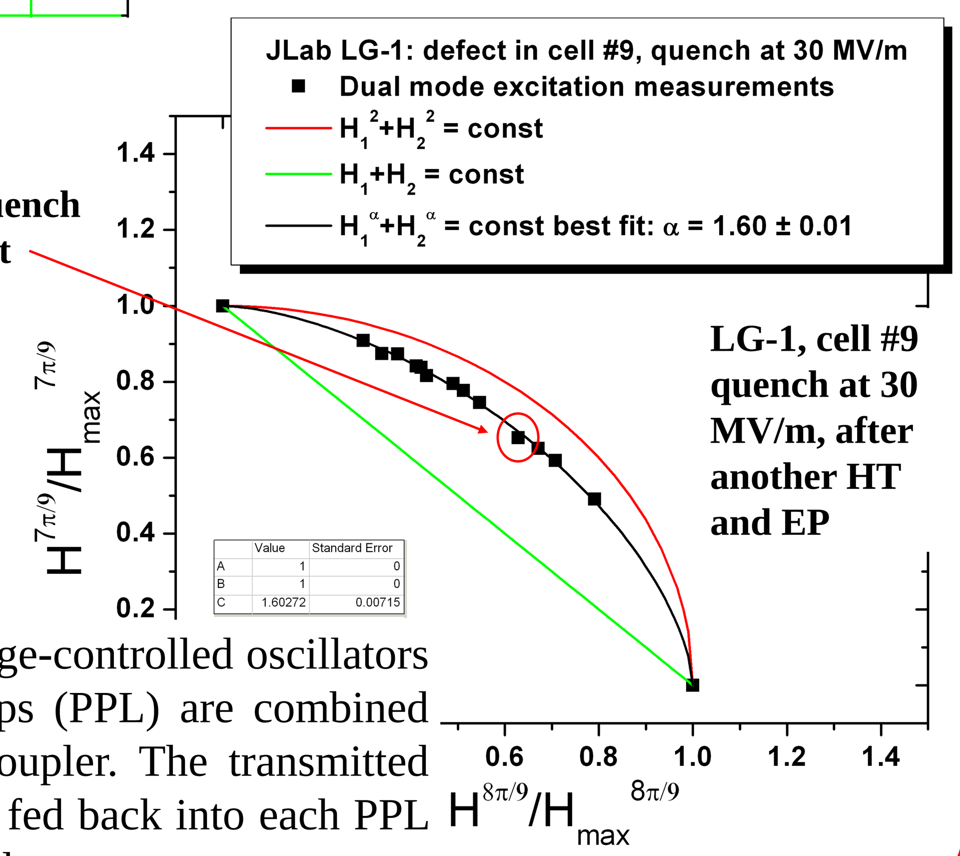
Methodology

- All pass-band modes are measured for a given cavity and the maximum gradient for each cell is determined.
- Quench locations are measured with OSTs and the cells responsible for quench in each mode are identified.



OST trace is a fingerprint of a quench, and it used during measurement to confirm quench location



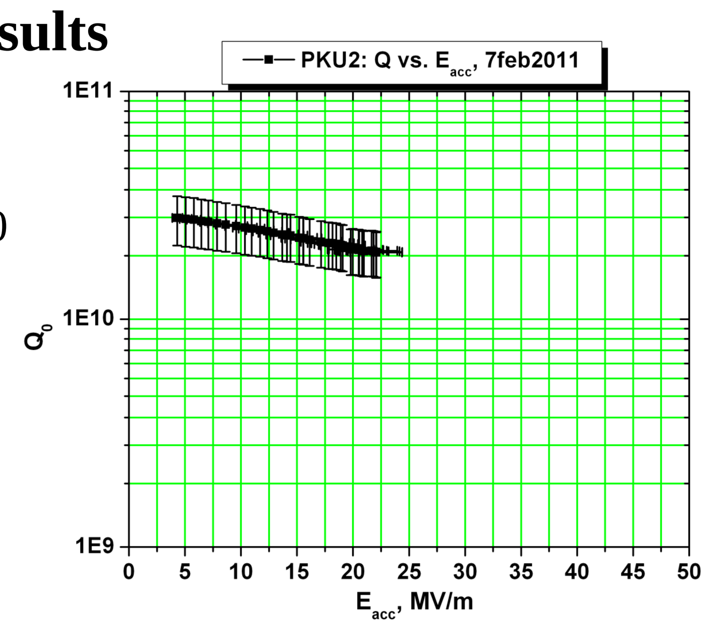


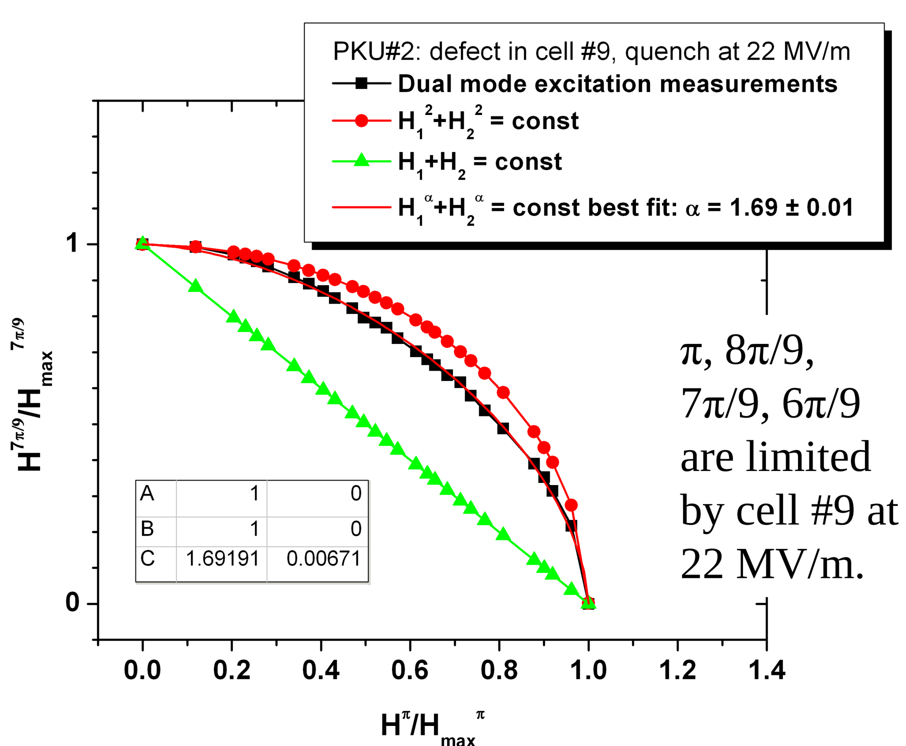
- Drive signals from two independent voltage-controlled oscillators (VCO) with independent phase-lock loops (PPL) are combined and fed into the cavity through input coupler. The transmitted signal is split three ways: two signals are fed back into each PPL and one part is sampled by a spectrum analyzer.

Results

PKU2 results

PKU2 large grain 9-cell ILC cavity has received 100 µm BCP + 600 °C x 10 hours + 80 µm BCP + 800 °C x 2 hours + 30 µm EP +120 °C x 48hours. In π mode the cavity was limited by a quench in cell #9 as identified by OSTs.

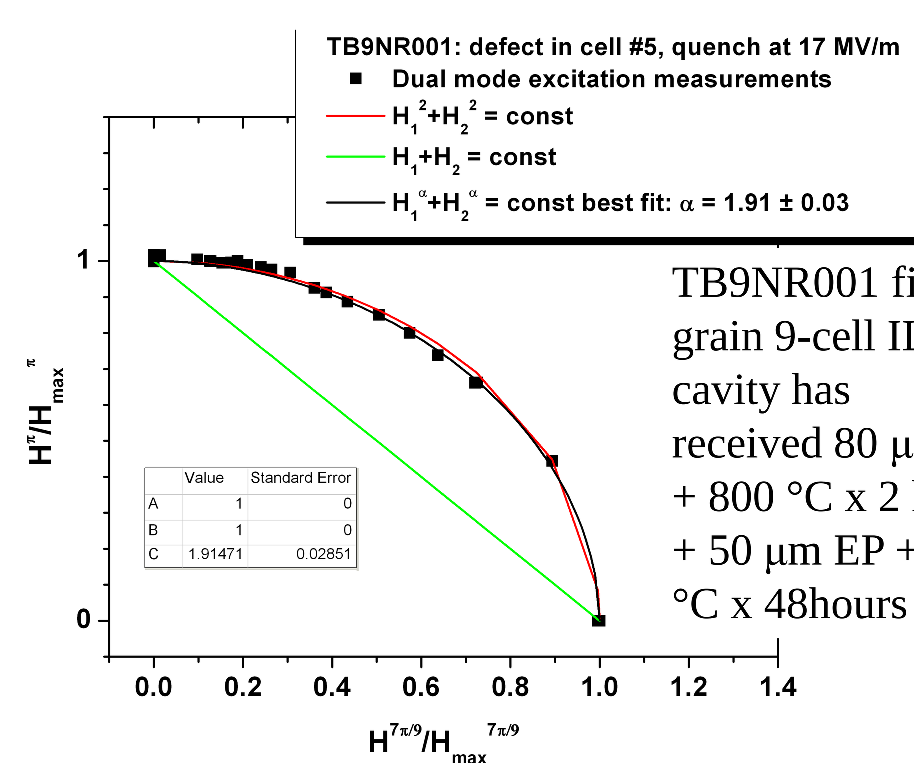




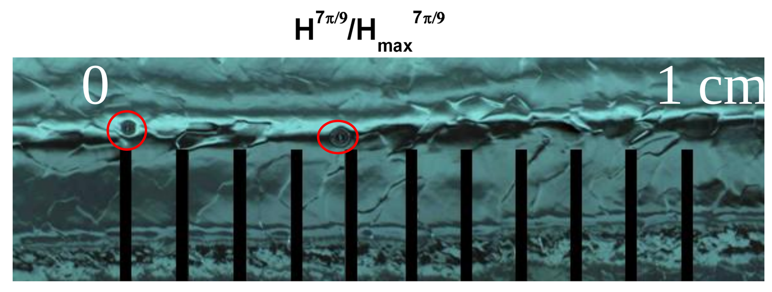
π, 8π/9, 7π/9, 6π/9 are limited by cell #9 at 22 MV/m.

TB9NR001 results

Twin cat-eye feature on the weld limits TB9NR001 at 17 MV/m after the standard processing. The best fit is 1.91 for this defect closest to the pure thermal quench, we've measured so far.



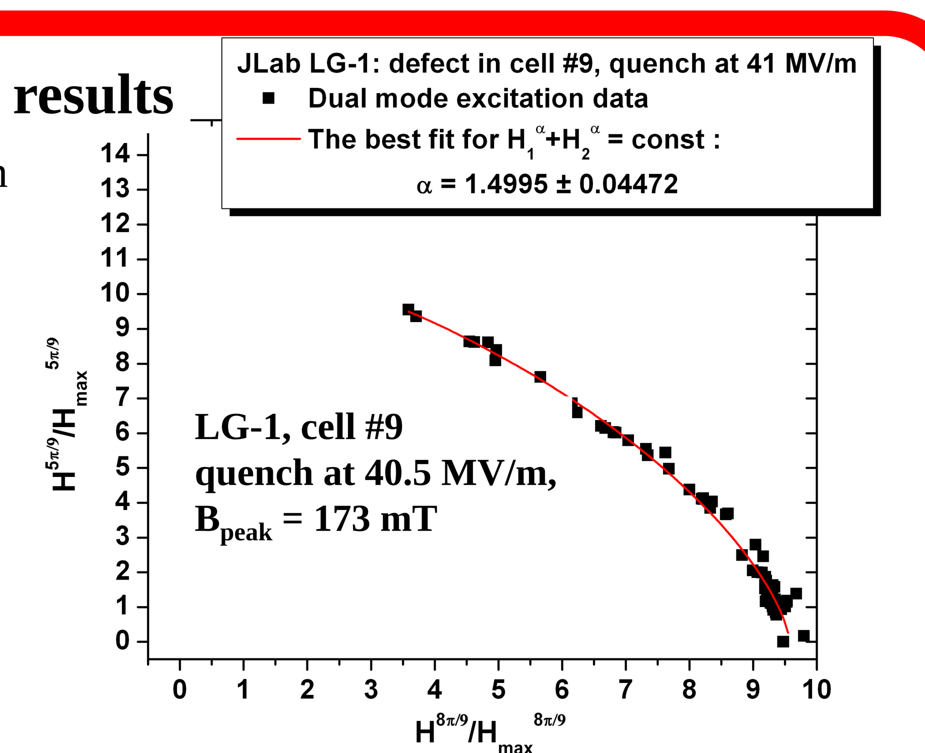
TB9NR001 fine grain 9-cell ILC cavity has received 80 µm EP + 800 °C x 2 hours + 50 µm EP +120 °C x 48hours

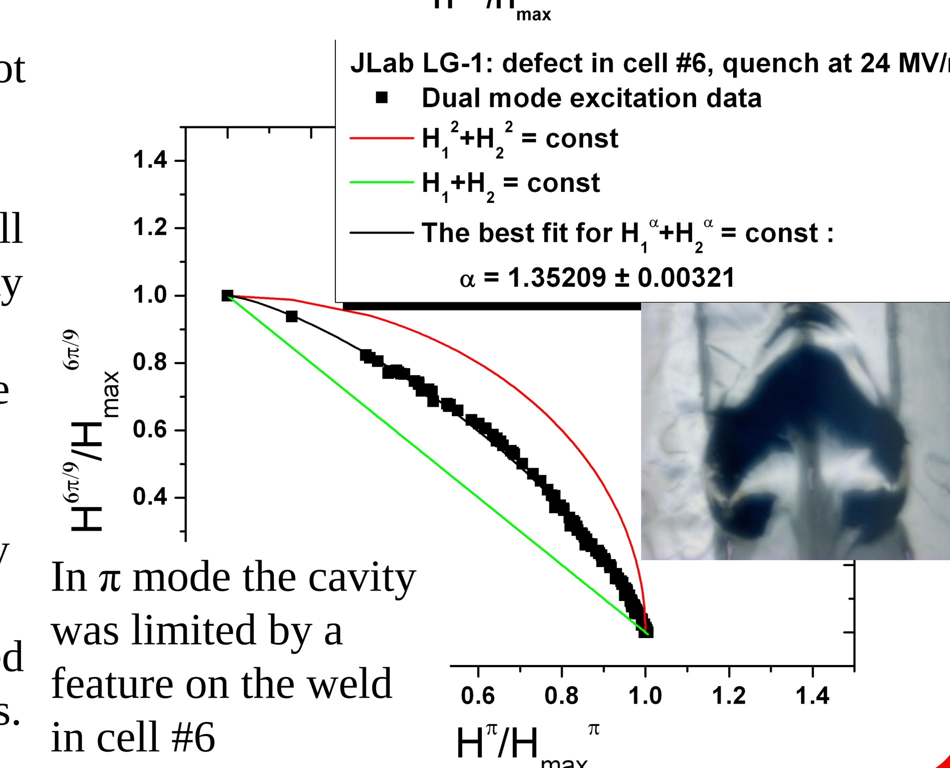


JLab LG-1 results

JLab LG-1 large grain 9-cell ILC cavity has received BCP + 35 µm EP +120 °C x 48hours + local grinding cell #5 + 85 µm EP +120 °C x 48hours

Cell #9 of JLab LG-1 was limited at 173 mT. However, dual mode fit of 1.50 is not the lowest exponent we've measured so far. The feature in cell #6, limiting the cavity at 102 mT has exponent of 1.35. We infer from the measurement that gradient significantly higher than 40.5 MV/m can be reached in ILC-shape cavities.





In π mode the cavity was limited by a feature on the weld in cell #6

Conclusions

We have studied thermal breakdown in several multi-cell superconducting radiofrequency cavity by simultaneous excitation of two TM_{010} pass-band modes. Unlike measurements done in the past, which indicated a clear thermal nature of the breakdown in SRF cavities, defects in modern SRF cavities present a more complex picture with interplay of both thermal and magnetic effects. The data for all defects can be characterized with a single parameter, exponent in quench field dependence. For defect that we've measured this exponents range from 1.4 to 1.9. Surprisingly, in JLab LG-1 that was limited at 40.5 MV/m, corresponding to Bpeak = 173 mT in 8pi/9 mode, dual mode measurements on this quench indicate that this quench is not purely magnetic, and so we conclude that this field is not the fundamental limit in SRF cavities. With further advances in preparation techniques such as chemical polishing and centrifugal barrel polishing SRF cavities will reach higher gradients.

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