ANALYSIS OF QUENCHES USING TEMPERATURE MAPPING IN 1.3 GHz SCRF CAVITIES AT DESY*

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Abstract

The local thermal breakdown (quench) behavior of one- and nine-cell SCRF Nb accelerator cavities is investigated systematically. For more than 50 cavities, in addition to the rf test results, temperature mapping data have been analyzed with respect to surface preparation, Nb material etc.. Results on rf properties, quench location and characteristic correlations are presented.

T-MAPPING SYSTEMS AT DESY

Presently, three different T-mapping systems for superfluid Helium are in use at DESY.

- Fixed, high sensitivity T-mapping system for single-cell cavities with 768 sensors on 48 boards (= 7.5 ° angle spacing) (Fig. 1a) [1]
- Rotating nine-cell T-mapping system with 128 sensors for quench detection (Fig. 1b) [2]
- “Quick” fixed T-mapping with 72 sensors at 24 angle positions for equator region (Fig. 1c).

All sensors are based on carbon resistors [3]. The block diagram of the multiplexed data acquisition is shown in Fig. 1d. The off-line analysis is based on in-house programming using LINUX PC applications.

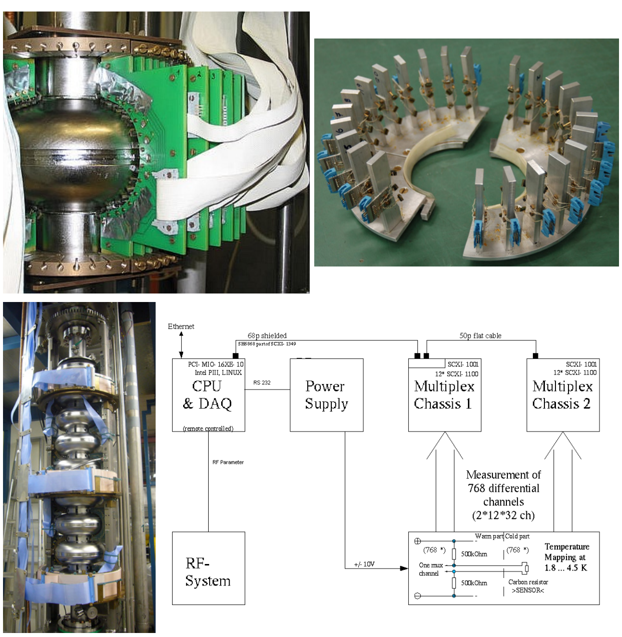

Figure 1: a) Single-cell T-map system (top left); b) rotating nine-cell T-map system (bottom left); c) “quick fixed” T-map (top right); d) data acquisition scheme (bottom right).

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LARGE GRAIN CAVITIES: ELECTRO-POLISHING vs. CHEMICAL ETCH

Cavities and Surface Treatment

Three nine-cell cavities (AC112 – AC114) [4] and five single-cell cavities [5] of TESLA shape were fabricated of two ingots of Large Grain (LG) Nb by W.C. Heraeus Co.. The cavities “AC” were machined and electron beam welded at Accel Instruments Co.; the cavities “DE” are DESY in-house production. Before the first cold rf test at least 120 µm of the surface have been removed by electropolishing (EP) or chemical etch (BCP) on all cavities. Also all cavities have been 800 °C vacuum annealed. After the final surface treatment by final EP or BCP, all cavities were assembled in a cl. 10/100 cleanroom and rinsed with ultrapure high pressure water of > 100 bar. Typical parameters of the low temperature bake procedure were (120 – 125) °C for 48 h for the nine-cells and (130 – 138) °C for 12 h for the single-cells. Both processes show comparable results. In Table 1 only the major preparations steps are shown; the full preparation and test summary can be found in [6].

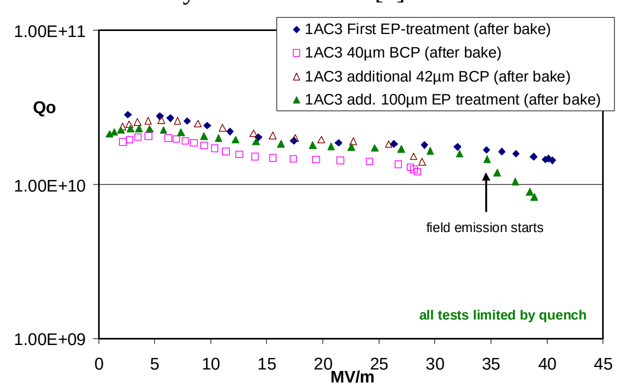

Figure 2: Q(E)-performance of an EP - BCP - BCP - EP preparation cycle of single-cell cavity 1AC3.

Preparation Dependency of Quench Gradient

As shown in Table 1 the influence of the final surface preparation of either > 40 µm removal by BCP or > 48 µm removal by EP on the Q(E)-performance has been investigated systematically. All test results of all 8 LG Nb cavities are given for $T_B = 2K$. Especially, the single-cells 1AC3 and 1AC4 went through full cycles of successive EP - BCP - EP treatments (Fig. 2). For both cavities a reproducible gradient gain of > 10 MV/m after EP compared to BCP is observed. A final BCP treatment applied on 6 cavities results in reproducible gradients of (25 – 30) MV/m limited by quench for all cavities. A final EP gives quench fields between (33 – 43) MV/m in 6 of 8 cavities. Two nine-cell cavities show low gradients limited by field emission and quench. The reason for the unusual behaviour is not understood yet. New surface treatments of both cavities are in preparation.

RF Properties of Large Grain Nb vs. Fine Grain Nb

In Table 2 the characteristic rf properties of LG Nb cavities are compared to the well-known fine grain material. Obviously, the characteristic scrf parameters, especially the quench field, Q-drop without field emission and field emission behaviour, are identical within the available test results. For the quench gradient of fine grain Nb cavities, after 800 °C firing + final BCP, not sufficient data are available at DESY.

With the given identical rf performance of fine and large grain Nb, now a large scale accelerator application of LG Nb cavities (e.g. for the European XFEL) depends only on the availability of high quality LG Nb, its cost and the cost-effectiveness of the cavity production.

Table 1: Simplified summary of preparation and test history on large grain cavities (not all cavity preparations and tests shown; all rf test results at T_B = 2 K).

		1AC3	1AC4	1AC7	1DE20	1DE21	AC112	AC113	AC114
EP before bake	Eacc	28 (FE)	29 (pwr)	-	-	-	-	-	-
	Qo	3e9	3e9	-	-	-	-	-	-
+ bake (+ HPR for 1AC3)		41 (BD)	37 (BD,fe)	-	33 (BD)	39 (BD)	-	-	-
		1,4e10	6,3e9	-	1,4e10	1,1e10	-	-	-
+ BCP (~40µm or pure BCP) + HPR		31 (pwr)	30 (pwr)	25 (BD)			30 (BD)	27 (BD)	29 (BD,fe)
		2,2e9	2,2e9	1,5e10			6,6e9	1,7e10	7,3e9
+ bake		29 (BD)	28 (BD)						
		1,2e10	1,2e10						
+ BCP (~40 µm) + HPR + bake		29 (BD)							+20 µm BCP: 27 (BD)
		1,4e10							1,6e10
+ EP (~100µm) + HPR + bake		39 (BD, fe)	41 (BD)	27 (BD, fe)			20 (FE)	+ 48 µm EP: 37 (pwr,fe)	14 (BD)
		8,3e9	1,3e10	1,5e10			1.9e9	6,6e9	1,6e10
+ EP (~20µm) + HPR +bake				43 (BD)			+90 µm EP: 17 (FE)	-	
				1,4e10			1,5e9	-	

Table 2: Comparison of characteristic scrf properties for large grain vs. fine grain Nb cavities.

	Quench gradient after final EP	Quench gradient after final BCP	**EP:** Q-drop before bake	**EP:** cure of Q-drop by bake	Characteristic rf parameters + residual resistance
Large grain Nb	(33 – 43) MV/m	(25 – 30) MV/m	Typically > 25 MV/m	yes	R_{res}, R_{BCS}, Δ/kT_c, medium field Q-slope + field emission behaviour **identical**
Fine grain Nb	(36 ± 4) MV/m	Data not sufficient	Typically > 25 MV/m	yes	

T-MAP ANALYSIS OF SINGLE- AND NINE-CELL CAVITIES

Localisation of Fabrication Problems

Most important is the localisation of fabrication and/or material problems in the TTF/FLASH nine-cell cavities. An example for the identification of a low gradient quench location at the equator is given in Fig. 3. The quench directly located on the equator weld indicates a problem during cavity fabrication, which requires further investigation of the weld procedure at the manufacturer. Furthermore, the improved optical surface inspection method has been applied to several nine-cell cavities recently [7, 8]. Many suspicious spots and surface anomalies have been found in the inspected cavities. Typically, correlations to the detected quench locations could be found. Next step will be the cutting-out of an identified defect region from a nine-cell cavity and material analysis of the defect.

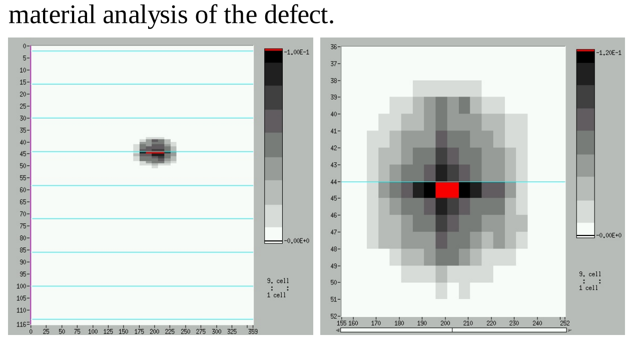

Figure 3: Identification of quench location at equator in cell 6 of nine-cell Z111 at 16 MV/m; left: Full rotating T-Map; right: Cell 6 with refined angle resolution.

General Observations

The analysed single- and nine-cell cavities fabricated of fine- and large-grain Nb with quench field > 25 MV/m , typically show the expected quench location in the high magnetic field region (Fig. 4 (right), Fig. 5 (left)). No systematic increased quench appearance on the equator weld could be found. In case of field emission, the characteristic heating of the iris region, often together with a trace to/in the equator region, is observed (Fig. 4(left)).

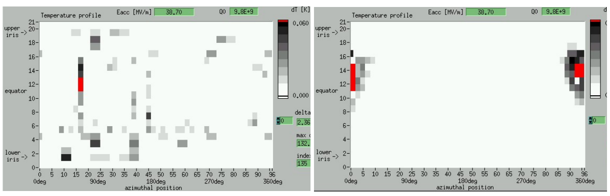

Figure 4: (left): Just below the quench field at 39 MV/m: typical field emission trace and heating at iris visible; (right): Quench at 39 MV/m located close above the equator (both T-maps taken in test 7 of single-cell 1AC3).

After an additional surface removal of several µm by EP or BCP, typically the quench location changes. In some cases the data are ambiguous or e.g. even after a 41 µm BCP the former quench location could be identified as a "hot spot" (Fig. 5 (right)).

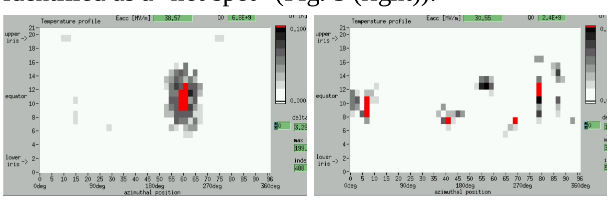

Figure 5: (left) Quench at 39 MV/m in single-cell 1AC4, test 6; (right): after 41 µm BCP a "hot spot" is visible at identical location in test 7, 1AC4.

Contrary to thermal conductivity model calculations based on the assumption of normal-conducting, lossy defects, often no clear pre-heating below the quench field could be observed at the quench location of single-cells (Fig. 4). Obviously, the nature of the defects responsible for the quench is not fully described by the above assumption and a more refined model is necessary.

Alternating Quench Positions

Rarely, the exciting observation of a changing or alternating quench position was made. By keeping the cavity in the self-pulsing quench and parallel continuous data sampling of the T-mapping system, in one single-cell three alternating quench locations at app. 40 MV/m could be found. This may be an indication of approaching the fundamental magnetic field limit, presumably combined with some magnetic field enhancement effects. As this measurement technique was not applied systematically to high gradient single-cells in the past, no information about the frequency of occurrence is available

CONCLUSION

Systematic investigations on Large Grain Nb cavities show a typical gain in quench field of > 10 MV/m after final EP compared to final BCP. Comparing of LG Nb cavities with fine grain cavities, no difference in the characteristic scrf properties, especially in quench field, can be found.

Applying T-Mapping is essential for an effective quench analysis. An identification of field emission induced quenches is possible. In nine-cell cavities material and weld seam problems can be localized as a pre-condition for further (optical) investigation. High sensitivity T-mapping in single-cells allows a locally resolved analysis of thermal effects. Contrary to the expectation by thermal model calculation often no pre-heating below the quench is observed. Alternating quench locations may indicate, that the fundamental field limit is approached, possibly combined with field enhancement effects.

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