WG1: High gradient R&D beyond field emission
Conveners: H. Padamsee, L. Lilje, J. Mammosser
TTC Meeting at DESY January 2008

Meetings were held for two half days on Monday 13:30-17:00 and Tuesday 9:00 – 12:30. During these two sessions, there were 12 presentations outlining the current and past data on quenches. These presentations along with extended open discussions on this topic, became the starting point for further work which is needed to gain ground in understanding the source or sources of quenches which limit cavity performances below what is desired. For these discussions, field emission was purposely omitted in order to clarify the technical task at hand of understanding quenches above 20MV/m where field emission should not be the cause of the quench.

High Lights From Data Presented and Following Discussions

- Examples were reviewed (from the literature) of classical defects that led to quench below 20 MV/m. These defects were located by thermometry on cavities which were later dissected to analyze the defect by surface analysis. Classical defect examples found were: large foreign particle (copper, 50 microns), Nb ball (50 microns), chemical stain with foreign metal inclusion (50 μm), and a pit with a sharp edge. All these defects showed pre-heating before quench. All these cavities were prepared by BCP.

- Results of a simple thermal model of defect breakdown were reviewed. The model predicts a large spread in quench fields due to the spread in defects sizes (and resistances). A 100 micron diameter normal conducting defect will quench at about 20 MV/m for 300 RRR Nb. The model also predicts that defects 20 microns in diameter lead to a thermal induced quench at 35 MV/m for 300 RRR Nb. Hence material defect control at the 20 micron level will be necessary to reach 35 MV/m.

- After excluding field emission limitations, the 9-cell data from DESY show that there is a large spread in quench fields. Similarly BCP 5-cell data from Jlab (especially from the recently prepared 40 re-furbished cavities) shows also a large spread in the quench field (these cavities were free of field emission). We need to understand the reasons for the large spread.

- Nearly 70% of the 9-cell tests (> 40 tests) from Jlab are limited by quench. Similar statistics is evident from DESY 9-cell tests once field emission is brought under control as for example by advanced methods such as ethanol rinsing.

- Comparison of the quench field for BCP and EP cavities built with the same RRR Nb reveals a higher (nearly x2) quench field for an EP prepared surface. This effect has been found with single cell and 9-cell data. Why EP surfaces reach a higher quench field is not yet understood; perhaps surface macro-roughness due to grain boundary steps plays a role.

- Data was presented showing in some cases quenches increasing or decreasing with subsequent EP processing
- Data was presented showing some cavities quench at the same gradient with additional surface chemistry
- Thermometry data from a single cell cavity repeatedly quenching, showed multiple (3) quench locations that changed after each pulse

Further understanding of the quench sources along with cavity preparation steps which were utilized will lead to way of increasing the reliability and reproducibility of cavity performances. The path forward to achieving this understanding must come directly from: 1) mining the current and future data of cavity tests with thermometry for hot spots and quench spots , 2) increasing the thermal data available on quenches, to look especially for the presence or absence of pre-heating 3) performing additional studies directed at resolving questions on topic related to cavity quenches, such as whether the quench field an location changes due to EP, baking and other treatments to be used for cavity preparation.

Mining Data

There is a strong need to collect and understand the current data that is available from all laboratories testing cavities, both single and multicell data relating to quenches. The thermometry data from cryogenic tests also needs to be understood and analyzed with respect to the nature of heating on cavity surfaces. There is currently not enough thermal data available due to the lack of thermometry systems at many institutions testing cavities.

Secondly the analysis of defects or hot spots seen when thermometry systems locate them are rarely analyzed to the level necessary to improve the knowledge of the source and or results from these type breakdowns. Most importantly a more systematic collecting of data is needed by all testing SRF cavities. Data collected must include details on the processes implemented, changes in quench performance along with diagnostic data and conclusions by the principle investigators. This data is necessary to analyze and test current theories of the causes and the nature of the mechanism.

One example of observations which need a more detailed analysis are quench locations which show no apparent pre-heating. Normal defects would show already some heating before the full breakdown occurs. The existing data needs a closer look.

Thermal Data Generated with Thermometry Systems

Currently the best method to identify the location of hot spots on surfaces during cavity testing is by thermometry systems. Data generated to date shows a verity of surface thermal features and events prior to and during quenches. These data can not be easily understood without further investigations aimed at understanding the quench mechanism.

Problem is only a few percent of cryogenic tests carried out are performed with thermometry due to the low number of system in use or available and due to the complexity and difficulty of preparation on cavities. More thermometry systems are needed to increase the data generated during cavity testing. Secondly a focused quench study program is needed to probe at the causes of quenches.

Performing Additional Studies Aimed at Understanding Quenches

Current data suggest that there are many types of cavity behaviors when it comes to quenches. Quenches can increase or decrease or stay fixed with subsequent chemistries on the cavity interior surfaces. One example was shown where there was large step (several 100 microns) at the quench site determined from taking a surface replica. Further BCP moved the quench site to another location with large step. Possible interpretation: there was no defect involved, a complete grain of pure Nb with sharp edges quenched. This may correlate well with the quench due to a pit with a sharp edge.

Quenches decrease the maximum reachable accelerating field with additional BCP etching after the cavity has been fully electropolished. This correlates with the general finding above that the quench field for EP cavities is about a factor of 2 higher than for BCP cavities. For large grain material this is not evident. Quenches have been shown to be caused by improper cavity fabrication procedures, mainly through contaminated welds. Surface anomalies have been identified by several investigation methods and in some cases they have been identified as the location of the quench and in other cases just identified as surface anomalies and no thermal data was collected and therefore there is no way of concluding with certainty that the quench was caused by the anomaly.

Data exists on large grain cavities with BCP and with high resolution thermometry. The quench field vs RRR should be compared for large grain with fine grain BCP cavities. Some data show higher quench fields for large grain niobium material.

An effort to understand early quenches above 20MV/m gradients has been started with this working group, therefore a more dedicated experimental effort should be identified and work started focused on the mechanisms causing early quenches. During this meeting several theories came forward to answer the cause of the early quenches and in order for investigations to start, detailed plans must be developed to address each theory. These plans may include: data analysis, special tests carried out, additional inspections methods and special fabrication procedures.

At the limit of our present knowledge, possible sources of quenches arise from material defects, manufacturing errors, chemical residues, large particles (> 10 micron) that enter the cavity accidentally, and surface roughness.

There is a strong coupling between the quench studies and the diagnostic studies of the WG2. Eddy current scanning, squid scanning, optical diagnostics and other tools will play a major role in understanding the sources of quench and in reducing the quench spread.

Preliminary Synthesis: Theoretical explanations and experimental data

Two overview tables have been generated. One contains the possible explanations for a pre-mature breakdown (Appendix 1). The table should be completed until the next TTC meeting to contain the most prominent effects and their manifestation e.g. signature in the temperature mappings or in the Q(E) curve.

The second table tries to categorize the major observations for the large number of experiments that have been performed to date. This categorization should make the comparison of data simpler. E.g. obvious contradictions in observations could lead to more detailed investigations.

Appendix 1: Table of Signatures for Various Theories

		Signature in Tests			
	Effects	**Temperature Mapping**	**Q(E) Curve**	**Other Parameters e.g. energy gap**	**Optical inspection**
Topology related	Flux penetration				
	Field enhancement	Heating should disappear after modification of area with field enhancement e.g. polishing			Should be able to locate problem areas after t-map
	Lower critical magnetic field	No pre-cursor, detailed comparison with surrounding material (BCS-behaviour)			
	Grain boundaries	Heating should disappear after modification of steps e.g. polishing or single-crystal			
	Pits (fabrication, preparation)	Heating should disappear after removal of pits, guided repair			
Chemical composition	Sulphite contamination				
	Interstitials (RRR degradation)				
	Grain boundaries				
	Foreign material	Location shows precursor	Shows slight Q-degradation just below final quench field		

Appendix 2: Current experience with surface treatments and fabrication

	Type	Remarks	Quench		Field emission		T-mapping		
			…max. Field	**Spread in field**	**Onset field**	**Spread in field**	**Pre-cursor**	**location**	**Reference**
Treatment	EP + short BCP	need to define short	reduces						> 20 um DESY
	EP + ethanol			no change	increases				DESY, Saclay
	EP + degrease	define type of degrease		no change	increases				Saito, Cornell, Jlab
	EP + H2O2				increases				Kako
	EP + MicroEP (3-5um, fresh)			smaller	increases				Saito
	Centrifugal Barrel polishing	need to compare CBP cavities' t-maps with others						should reduce BD locations on weld	Saito
Fabrication	Seamless cavities								
	Welded cavities								
	Fine-grain								
	Large-grain							Do not show enhancement at Grain Boundaries	JLab, Cornell
	Single-crystal								
	Sheet textures								