Experimental Investigation of Quenches in Superfluid He of TESLA 9-Cell Superconducting Cavities

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ABSTRACT

We have experimentally investigated the quenches of some TESLA 9-cell superconducting accelerating cavities at Eacc above 12 MV/m in superfluid liquid He (He II). The quench origins were located and quench type was identified. The quench dynamics, normal zone propagation, and quench recovery were observed. Comparisons of quenches of TESLA 9-cell cavities in He II and in subcooled LHe were conducted. Experimental simulation of the heat transfer between cavity surface and He II during quench has been performed. A guided reparation of quenched cavity was initially practised.

INTRODUCTION

The TESLA superconducting cavity (about 1 m-long) has the largest cell number within low frequency cavities (L-band) and needs to reach the highest operating accelerating fields Eacc (15 MV/m for TESLA Test Facility and 25 MV/m for TESAL). Five TESLA 9-cell cavities have been tested and are all limited by quench at about Eacc: 12, 12, 22, 22 and 22 MV/m respectively [1, 2]. All of the cavities were high temperature treated with Ti-purification (RRR values are about 500).

There are three factors that influence the cavity quench fields. First, heat production is determined by defect size, defect resistance and the level of RF fields. The heat transported to surrounding areas is dependant on thermal conductivity of cavity materials, wall thickness and the heat transfer coefficient between the cavity and LHe II. Finally, the power dissipated in the neighboring Nb of defects is a function of RF frequency, temperature and residual resistance.

To overcome quenches, we experimentally investigated the performance of these cavities, quench related physics phenomena, quench dynamic progress and the guided reparation of a quenched cavity by means of a specially developed rotating T-R mapping system [3]. In the mapping system, each cell surface of the cavity is longidudinally covered by 14 surface scanning thermometers and 4 photodiodes. More than 10,000 spots on a cavity surface can be analysed in one turn with 5^{o} stepping.

IDENTIFICATION OF QUENCH ORIGIN & QUENCH CHARACTERISTICS

The TESLA 9-cell cavity D-4 has been heat treated with Ti-purification at 1400^{o} C for 4 hrs and a test sample has a RRR above 500. We then removed 80 μm of material from the inner RF surface and 30 μm from outer side by chemistry, followed by high pressure rinsing. It finally reached Eacc = 12.5 MV/m with a Q = 7 x 10^{9} at 1.8 K and was limited only by a quench. Fig. 1(A) shows the overall RF performance.

The entire surfaces of the 9-cell cavity was scanned by the rotating T-R mapping system. The quench was identified in cell-3. The quench origin was located in a strongest heating area centred at the equator (thermometer-7). The entire heated area crosses over 70 degrees in azimuth and 12 thermometer in longitudinal, as shown in Fig. 1 (B). We quenched the cavity several times and found the heating profil remained the same as in Fig. 1(B). The heated area was limited only in the cell-3. The quench did not propagate to the adjacent cells.

To identify whether the quench is thermal breakdown or magnetic breakdown, the heating profile of quench origin before breakdown was studied. We turned the T-R mapping on at the quench origin and carefully measured the temperature maps as functions of Eacc before quench,

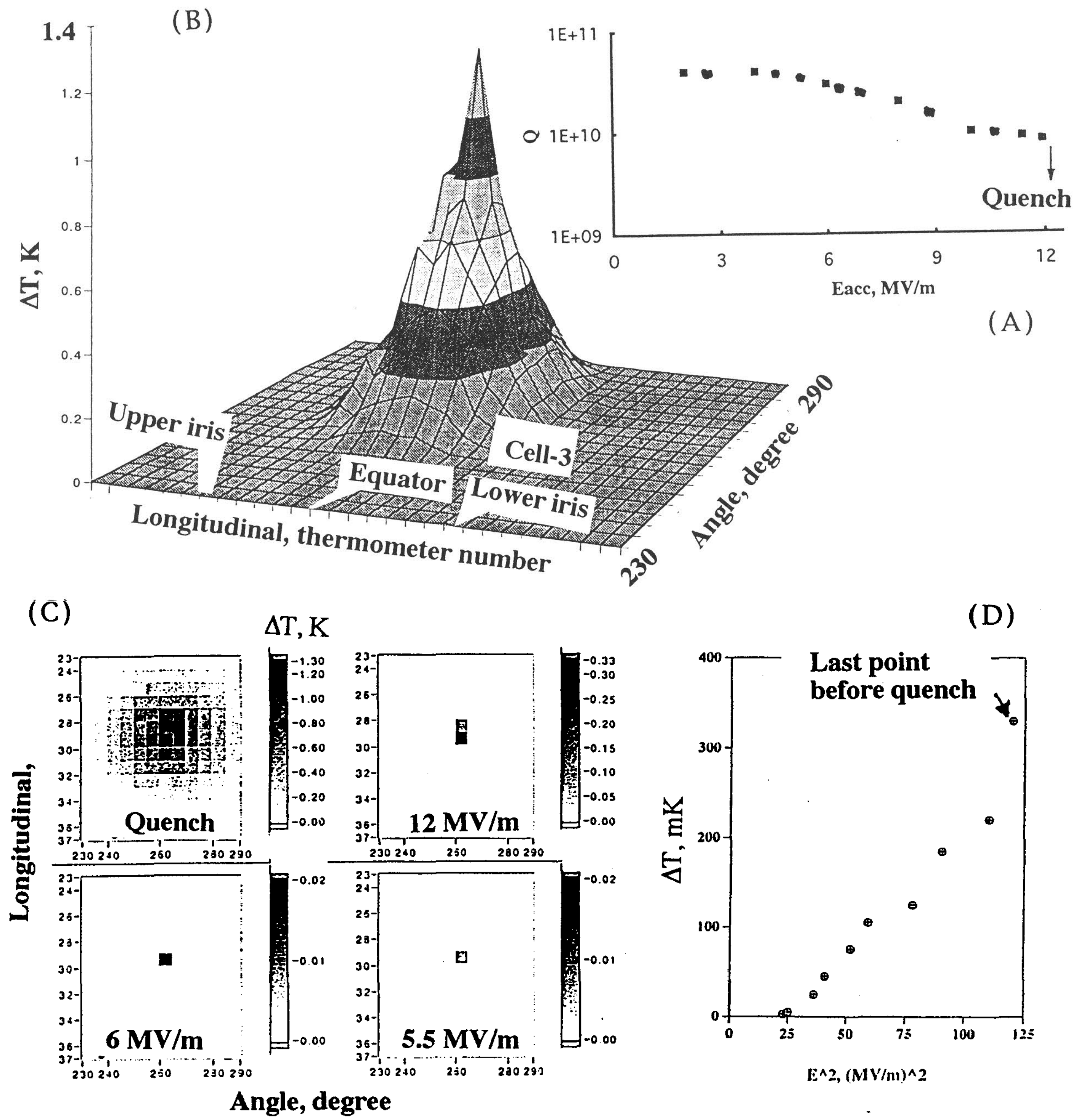

Figure 1. (A) Overall RF performance of cavity D-4; (B) The heated area of cavity D-4 during quench at 12 MV/m in He II; (C) T maps during and before quench; (D) ΔT at the quench origin as a function of $(Eacc)^2$ before quench.

as shown in Fig. 1 (C). In Fig 1. (D), the ΔT at quench origin is approximately, linearly proportional to $(Eacc)^2$ before quench. This heating profile indicates that the quench is a thermal breakdown with a nature of normal conductor since a magnetic breakdown would not show a strong pre-heating.

HEAT TRANSFER BETWEEN CAVITY & He II BEFORE-DURING QUENCH

Experimental simulation to understand the heat transfer between surface of an SRF cavity and He II before and during quench has also been conducted [4]. The thermometers are mounted in the real operating conditions of the scanning device for cavity test. The heat flux through the surface varied from tens mW/cm^2 to 2.8 W/cm^2. The temperature was measured by the surface

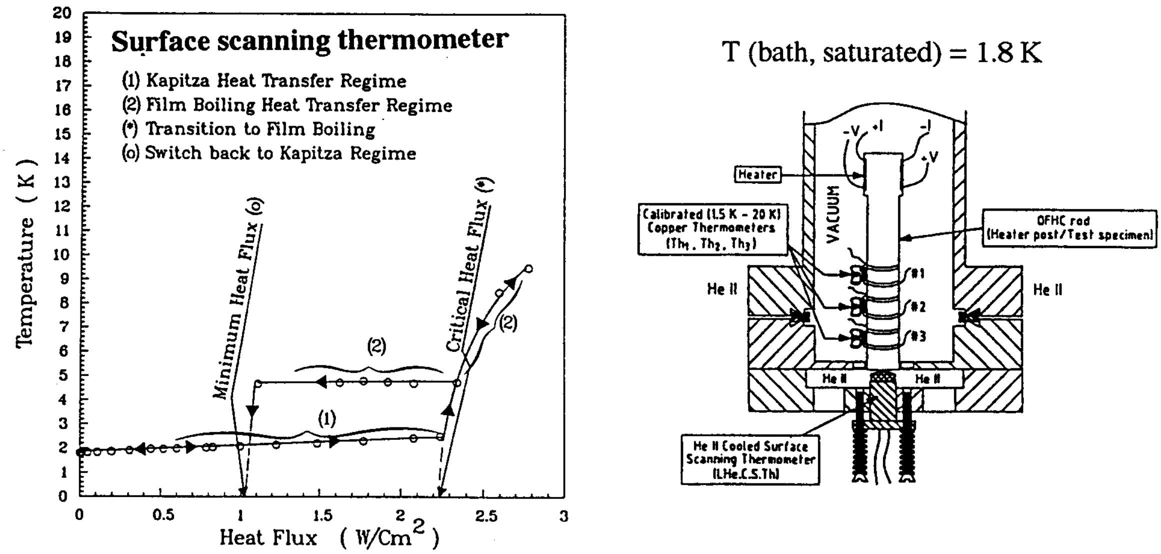

Figure 2. Scheme of a device for study of surface heat transfer in LHe II; (B) Heat transfer between a heated surface and He II with large heat fluxes. The transition between the Kapitza regime and film boil is identified.

scanning thermometer as functions of the heat flux. Fig 2. presents one of the test results. It is observed that the Kapitza heat transfer regime is effective until 2.2 W/cm^2, a critical point. Heat transfer is then governed by film boiling as heat flux dQ/dt > 2.2 W/cm^2. In the regime, temperature increased sharply. When heat flux was reduced from film boil regime, a transition regime was observed before the heat transfer switched back to Kapitza behaviour. The minimum heat flux for returning to Kapitza regime is about 1 W/cm^2.

From the temperature map measured in Fig 1. (D), the second point before quench shows ΔT of about 220 mK which represents a heat flux of 0.75 W/cm^2 that is in Kapitza regime. The last point before quench shows ΔT of about 320 mK which indicates a heat flux of 1.2 - 1.3 W/cm^2 that is in the transition loop. The temperature map measured during quench, Fig 1. (B), proves that a strong film boil takes place between the cavity surface and He II with ΔT > 700 mK and average heat flux much larger than 2.5 W/cm^2.

COMPARISON OF CAVITY QUENCHES IN SUPERFLUID LHe AND SUBCOOLED LHe

We studied the quench decay rate, normal zone propagation, ΔT as a function of time and quench recovery. The study was carried out with cavity D-6 of the second test both in superfluid He and in subcooled LHe. Fig. 3 (A) shows overall RF performance respectively at 1.8K with quench Eacc: 12.6 MV/m, Q = 1 x 10^{10} and at 2.3K with quench Eacc: 11.5 MV/m, Q = 3x10^9.

The quench was found in cell-5 and centered longitudinally around thermometer 4 and 110^o in azimuth. The thermometer system was turned and fixed directly against the quench origin with 14 thermometers covering longitudinally over each cavity cell. Then the RF power was turned on in CW mode and the self-pulse quench & quench recovery of the cavity were observed. RF measurement shows the quench decay (dissipation of 1/2 stored energy) time is 1.4 ms at 12 MV/m in He II.

Fig. 3 (B) & (C) shows the longitudinal temperature distribution as a function of time over quench origin during self pulse quenches under CW RF power respectively at 1.8 K and 2.3K (subcooled, P = 0.3 atm.). In both cases, normal zones are limited within one cell. The heated area covered 2/3 of the cell-5 in longitudinal at 1.8K, while most of entire longitudinal was covered by heated area at 2.3K. In terms of self-recovery time (heated areas disappeared) it

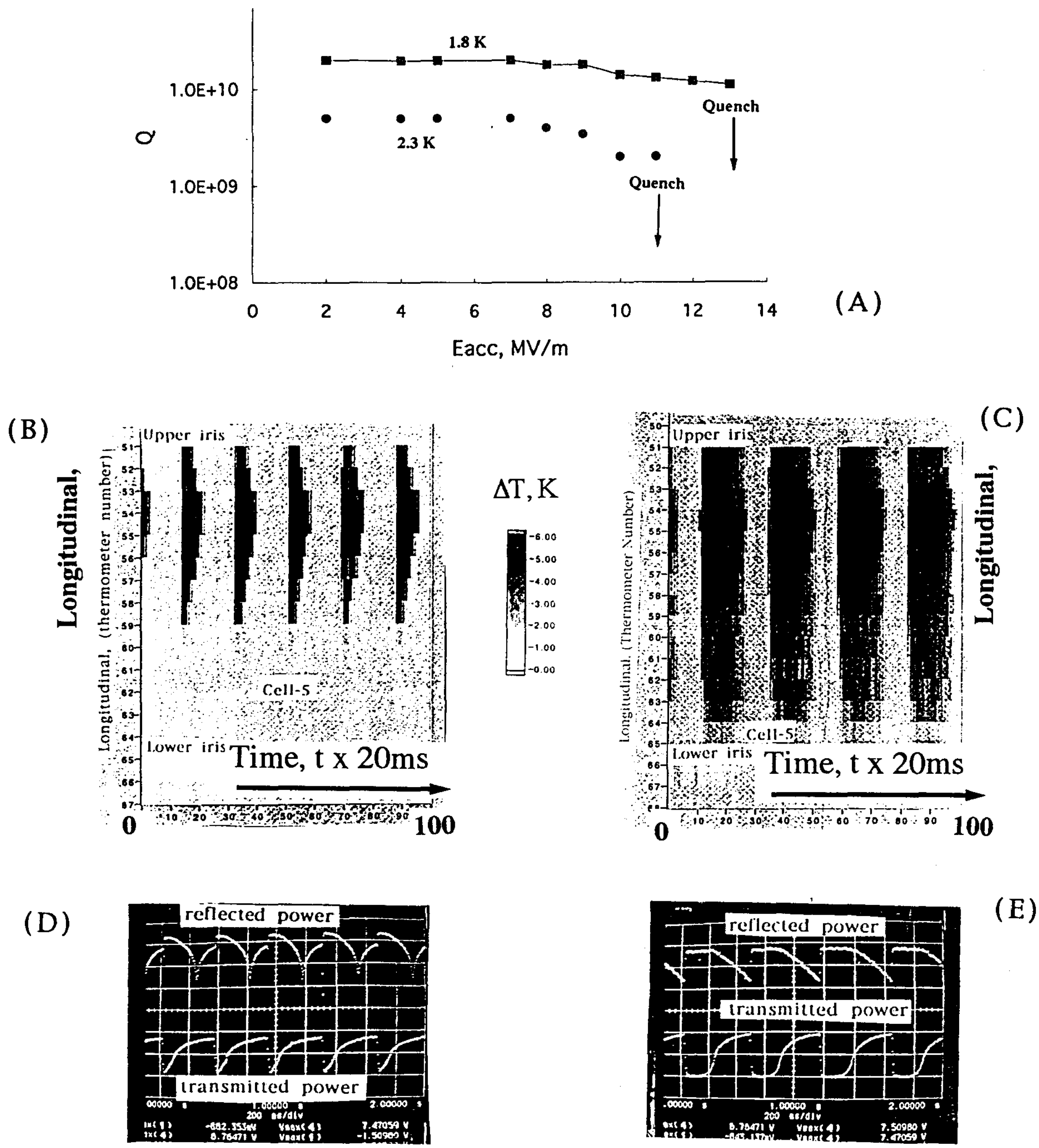

Figure 3. (A) Overall RF performance of cavity D-6 both in He II and normal LHe; (B) ΔT as a function of time in He II longitudinally fixed over quench origin during self pulse quench and-recovery; (C) ΔT as a function of time in subcooled LHe longitudinally fixed over quench origin during self pulse quench and-recovery; (D) Pt and Pr in He II; (E) Pt and Pr in subcooled LHe.

takes 140 ms in He II and 340 ms in subcooled LHe. With self-recovery, the cavity can remain in a superconducting state before the next quench, 240 ms in He II and 140 ms in subcooled LHe (Pf=120W). Fig 3. (D) & (E) shows the accordingly transmitted and reflected power recorded on oscilloscope during cavity self pulse quenches in He II and subcooled LHe respectively.

INITIAL PRACTICE OF GUIDED REPARATION OF A QUENCHED TESLA CAVITY

The TESLA 9-cell cavity D-6 which had the same preparation as D-4 reached Eacc = 12.5 MV/m and was also limited only by a quench. In the first test of D-6, the T-mapping located a strong heating next to the equator of the cell-5 longitudinally at thermometers 6-7-8 and between 15° to 25° in azimuth. Optical observation after test showed an irregular area on the inner surface in the region. An initial reparation with the grinding of the suspected area was performed followed by chemistry treatment and high pressure rinsing. This cavity was tested after reparation and the original quench location disappeared indicating the guided reparation was successful. In the test, we found another new quench location which is about 90° away and 5 cm longitudinally above the previous quench origin. It is believed that there are several irregular areas on the surface causing similar quenches. We will study reparation techniques to further improve the performance of quenched cavities.

CHECK POTENTIAL QUENCH SITES AT HIGHER FIELDS WITH DIFFERENT RF FIELD MODES

We normally test cavities in the accelerating mode, π-mode. When a TESLA 9-cell cavity was quenched at relatively lower fields (e. g. Eacc < 15 MV/m), the tests were sometime expanded to other modes in order to investigate the surface qualities in other cells at higher field levels while lower fields were remained in the quenched cell. We tested the cavity D-6 and found the quench taken place in cell-5 at Eacc = 12.5 MV/m. During test in π-3 mode, the equivalent Eacc raised to 17 MV/m in cell-3 and cell-7. We found a new quench location in cell-3 at 17 MV/m. Using this approach, a 9-cell cavity can be tested in all the 9 modes existed in the TESLA 9-cell cavity to further explore the cavity performance.

DISCUSSION

1. Pre-heating measured in quench origin of cavity D-4 is proportional to ($Eacc^2$) indicating the quench is thermal breakdown, and not magnetic breakdown. The ($Eacc^2$) heating also indicate the foreign enclosure (or defect) is normal conductivity in nature.
2. High RRR materials will help cavities undertake the ($Eacc^2$) heating. Deep chemistry will help take certain metallic enclosures with surface layers away from the cavity and reduce the probability of quench. Other cleaning techniques (such as clean room and high pressure rinse) are helpful in removing foreign quench agents.
3. The heat transfer between cavity surface and He II are governed by film boil during cavity quench. The critical heat flux from Kapitza regime to film boil is about 2.1 w/cm^2. The minimum heat flux back to Kapitza regime is about 1 W/cm^2.
4. In TESLA 9-cell cavity structure, a quench is limited within the cell of quench origin and does not propagate to the adjacent cells. The decay time for deposition of half stored energy is about 1.4 ms at Eacc = 12.5 MV/m.
5. The quench heated area is much larger in subcooled LHe than in He II. During self pulse quench-recovery, it take 140 ms for recovery from quench in He II & 340 ms in subcooled LHe.

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