THERMAL QUENCH PHENOMENA ON THE 1.3 GHZ HIGH GRADIENT SUPERCONDUCTING CAVITIES

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Abstract

The temperature dependence of the quench field was investigated between 1.8 K and 4.2 K using the 1.3 GHz single-cell niobium cavities. The location of the thermal quench was identified by the carbon thermometries, and the inner surface of the heating region was carefully inspected. In the cavities having high quench fields, a sharp drop of the quench field was clearly observed just at λ-point. The temperature rise on the seam of electron beam welding was observed in the cavities having low quench fields. A Q-switch phenomenon was observed in one cavity.

1 INTRODUCTION

In superconducting cavities, the maximum accelerating gradient (Eacc,max) is limited by either electron field emission or thermal quench. Recently, an onset field of field emission has been remarkably increased by an improved clean environment and careful handling, especially by an application of high pressure water rinsing (HPR) [1], [2]. After a final cleaning by HPR, the Eacc,max of 26 MV/m was achieved in the 1.3 GHz 9-cell cavity for TTF at DESY [3], and the Eacc,max of 43 MV/m was attained in the 1.3 GHz single-cell cavity at CEBAF [4]. In each cavity test, the Eacc,max was achieved with no field emission.

At KEK, a series of cavity tests is being continued to achieve higher accelerating gradients and to study phenomena at high gradients. Ten single-cell cavities were made from three different niobium materials (RRR = 100, 200 and 350) and tested repeatedly with surface preparation using HPR. In the results till 1995, it was shown that the accelerating gradient of 30 MV/m had been routinely achieved with 35 MV/m as the maximum gradient and the Eacc,max had been limited mostly by thermal quench [5]. In 1996, the Eacc,max of 40 MV/m was achieved in the first test of one cavity, in which heat treatment at 1400^{o}C was carried out for half-cells before electron beam welding (EBW) [6].

As mentioned above, thermal quench is currently a remaining obstacle after field emission has been suppressed. It is generally believed that thermal quench is caused by surface defects such as inclusions, scratches, welding imperfections, dust contamination and chemical residues produced during manufacture and surface preparation. To make clear the nature of surface defects limiting the Eacc,max and to understand the mechanism of thermal quench are essential in the achievement of a further high accelerating gradient. The investigations of thermal quench phenomena are reported in this paper.

2 TEMPERATURE DEPENDENCE OF QUENCH FIELDS

Firstly, an attainable gradient in a defect free surface (no local concentration of a residual resistance) is estimated by a simple one dimensional model. Thermal balance between heat production by rf loss and cooling by liquid helium is determined by an rf surface resistance (R_S), a thermal conductivity in niobium (λ), a heat transfer in the boundary of Nb/He (H_k, Kapitza conductance, in He-II and C_I in He-I) and a bath temperature of liquid helium. These important parameters strongly depend on the temperature. A critical magnetic field (H_c), a film boiling limit (Q_{fb}) and global heating [7] are considered as the causes of the limitation. Global heating accompanies with a steep deterioration of Q_0 values. In the defect free case with our cavity parameters, the quench field is expected to be 44 MV/m at 1.9 K by $H_c(0)$ of 2000 Oe and about 19 MV/m at 4.2 K by Q_{fb} of 0.2 W/cm^2. If either λ or H_k in a real cavity is lower than an experimental value in the sample tests, the quench field in He-II will be reduced by global heating; e.g., 40 MV/m with λ = 4 W/mK and H_k = 0.2 W/cm^{2}K at 1.9 K.

The temperature dependence of the quench field between 1.8 K and 4.2 K was investigated in four

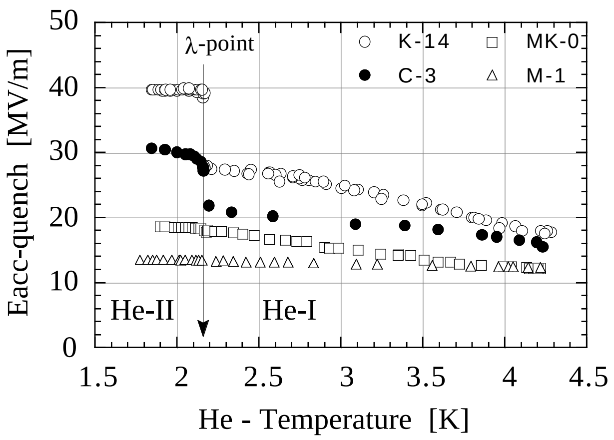

Figure: 1 Temperature dependence of the quench field between 1.8 K and 4.2 K in four cavities.

cavities, as shown in Figure: 1. The M-1 and MK-0 cavities were made from the same niobium material with an RRR of 100. The heat treatment at 1400^{o}C was carried out only in the M-1 cavity. The C-3 cavity was made from an RRR=350 niobium. These cavities have been tested repeatedly with occasional additional surface removal by chemical polishing, CP. However, improvement of the quench field has not been seen in spite of heavy polishing of total 350 ~ 500 μm; 11.4 ~ 13.6 MV/m in the M-1 cavity, 17.5 ~ 19.5 MV/m in the MK-0 cavity and 31.0 ~ 33.0 MV/m in the C-3 cavity. The K-14 cavity was a virgin cavity fabricated after heat treatment at 1400^{o}C in half-cells [6].

The Q_0 - Eacc plots in the latest test of the M-1 cavity are shown in Figure: 2. Though the Q_0 values at the quench field were decreased with increasing the temperature, the change of the quench field was slight from 13.6 MV/m at 1.8 K to 12.2 MV/m at 4.2 K. Temperature rises due to thermal quench were observed on the EBW seam at the equator by the carbon thermometries. The thermal quench occurred always at the same location between 1.8 K and 4.2 K. The inner surface was inspected by a CCD camera with a magnification of 50. Some welding imperfections (porosities of 0.1 ~ 0.3 mm) as shown in Figure: 3 were found around the quench location.

In the MK-0 cavity, the quench field was 18.6 MV/m at 1.8 K and were gradually decreased with the change of temperature. Finally at 4.2 K, it reached to the same field level as that in the M-1 cavity, (~12 MV/m). Temperature rise due to thermal quench was observed on the EBW seam at the equator, and the quench location was the same place between 1.8 K and 4.2 K. However, any visible defect was not identified around the quench location. The reason for the low quench field in this cavity is not clear. Possible explanations might be invisible welding imperfections or a low RRR material.

In the C-3 cavity, some increase of the quench field was seen below λ-point with cooling down of bath temperature. A sharp drop of the quench field from 30 MV/m to 20 MV/m was observed just at λ-point. The quench fields above λ-point were monotonically decreased to 16 MV/m at 4.2 K. Temperature rise was observed not on the EBW seam but at the upper-side half-cell in the

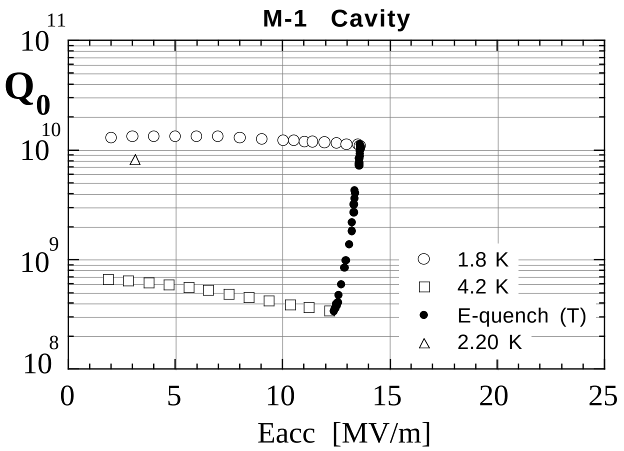

Figure: 2 The Q_0 - Eacc plots in the test of the M-1 cavity.

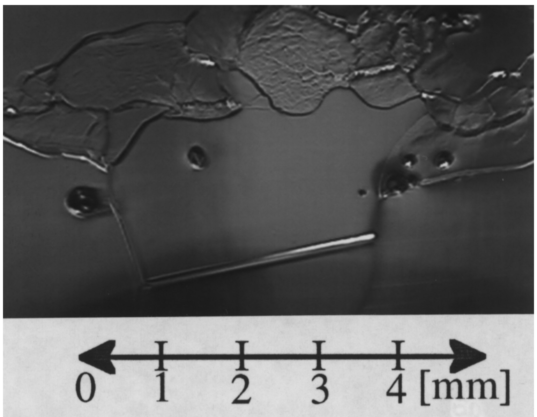

Figure: 3 A photograph of the welding imperfections, porosities on the equator EBW seam, found at the heating region in the M-1 cavity .

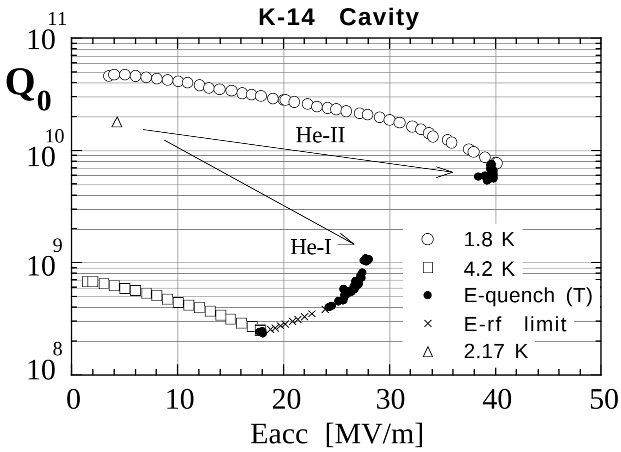

Figure: 4 The Q_0 - Eacc plots in the test of the K-14 cavity.

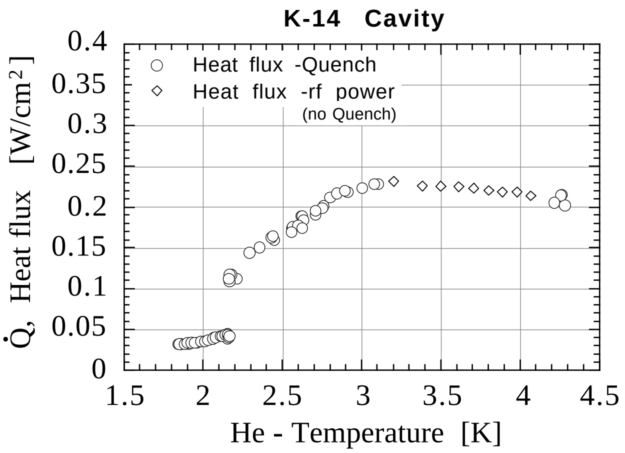

Figure: 5 Temperature dependence of the heat flux at the quench fields.

vertical test. The thermal quench occurred at the same location just below and just above λ-point, but the quench location moved to the lower-side half-cell at 4.2K.

The quench field of 40 MV/m, which is very close to the value calculated in the defect free surface, has been achieved in the K-14 cavity. The quench field was nearly constant below λ-point and drastically fell down from 40 MV/m to 28 MV/m just at λ-point, as similar to that in the C-3 cavity. The Q_0 value at the quench field also jumped at λ-point, as shown in Figure: 4. These features are probably due to the difference in cooling capacity and limiting mechanism between He-II and He-I, however were not seen in the M-1 and MK-0 cavities having low quench fields. The quench location below 2.1 K was observed at the region with a high rf surface current in the lower-side half-cell. However, the quench location was moved to the upper-side half-cell around λ-point, and was changed again to another location of the lower-side half-cell at He-I temperature. Even in the defect free cavity, the Eacc,max is limited by film boiling limit above λ-point, and the quench is liable to happen in the lower-side half-cell facing to He downwards. The heat flux at the quench fields is calculated with a surface peak magnetic field (H_{sp}) assuming an uniform rf surface resistance; $Q_{fb} = 1/2\ R_s\ H_{sp}^2$. The temperature dependence of the heat flux at the quench fields is shown in Figure: 5. It is seen that Q_{fb} is about 0.2 W/cm^2 at 4.2 K, then an attainable gradient at 4.2 K will be 22 MV/m even in a 508 MHz cavity with a lower BCS surface resistance.

3 Q-SWITCH

The M-5 cavity with a waveguide input coupler was newly fabricated having its external Q value of 1×10^5. The cold test was carried out after surface removal of about 230 μm by CP and hydrogen degassing at 760^{o}C for 5 hours. The waveguide input port was terminated with a niobium plate, and the rf power was fed by a coaxial coupler installed in the opposite side beam tube.

As shown in Figure: 6, the Q-switch was observed not only in the first test but also in the second test after additional 30 μm CP. The initial Q-switch occurred at 10.5 MV/m in both tests, furthermore, the next Q-switch was observed at the same field in the second test. Temperature rises at thermal quench were observed on the EBW seam at "the iris". Several sputtering balls as shown in Figure: 7 were found on the inner surface of the quench location.

It is supposed that the thermal contact between the sputtering balls and the niobium wall might be not sufficient to keep a superconducting state. Therefore, the additional rf loss at the field of Q-switch is considered to be due to the transition from a superconducting state to a normal conducting state at the defect surface. The thermally isolated normal conducting region at the iris might be stable because of a low rf surface current in comparison with that at the equator.

* ; MHI, Mitsubishi Heavy Industries Ltd.
** ; Nomura Plating Co., Ltd.
*** ; Tokyo Denkai Co., Ltd.

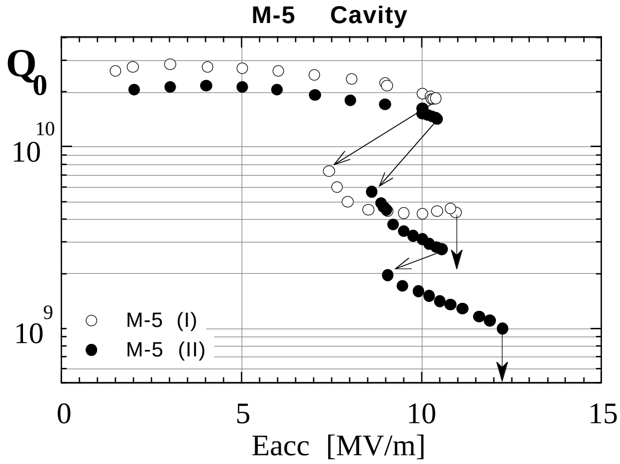

Figure: 6 The Q_0 - Eacc plots (1.8 K) in the tests of the M-5 cavity, in which the stepped drop of the Q_0 value was observed.

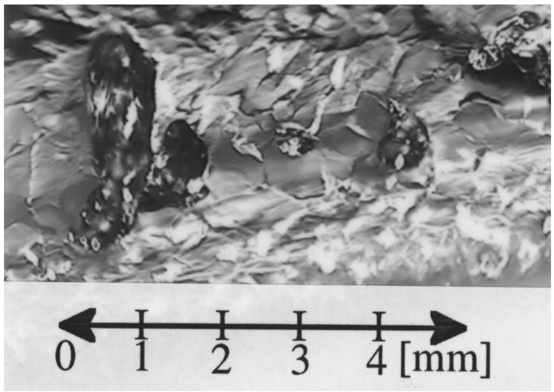

Figure: 7 A photograph of the sputtering balls on the iris EBW seam found at the heating region in the M-5 cavity.

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