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Activities of High Gradient SC Cavities at KEK

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Abstract

In a series of cavity tests on 1.3 GHz single-cell cavities, the main progress was that the problem of Q_0-deterioration after breakdown was settled and accelerating gradients of 30 MV/m were reproducibly achieved. Improvement of surface preparation techniques and a clean environment, development of a seamless cavity and fundamental studies of niobium materials are continuing at KEK.

1. Introduction

The development of high gradient superconducting cavities is essential for their applications in future accelerators, such as FEL drivers, proton LINACs for neutron sources and TESLA for an e+/e- linear collider. The development of 1.3 GHz niobium superconducting cavities was started in 1991 at KEK. An experimental hall was built for this purpose. A clean room (class 10) for assembly and a vertical cold test stand including a helium pumping system and an rf measurement system were constructed. Thirteen single-cell cavities and two nine-cell cavities were fabricated at CEBAF, MHI and KEK. A vacuum furnace for high temperature heat treatment at 1400°C (HT), a high pressure water rinsing system with 85 kg/cm^2 (HPR) and a temperature mapping system consisting of 684 carbon thermometers were developed. A series of cavity tests is continuing to achieve higher accelerating gradients and to study phenomena at high gradients. Up to now, 70 cavity tests on 13 single-cell cavities have been carried out. The history of the cavity tests over five years is summarized in Fig. 1. HT was carried out in the specified cavities, and HPR was added as a standard procedure in 1994. In the early stages of the tests, the obtained maximum accelerating gradient (Eacc,max) gradually increased by an improvement of the surface preparation. However, one serious problem encountered was the fast breakdown and resultant Q_0-deterioration due to field emission. This phenomenon was reported in the previous SRF workshop at CEBAF [1, 2] and was named "Japanese Q-disease". In this paper, the present status of the cavity tests, activities in the R & D program and a future plan are reported.

2. Q_0-deterioration after breakdown

Q_0-deterioration after breakdown is shown in Fig. 2, and the typical features of this phenomenon are summarized as follows. No field emission was observed during the initial Q_0 - Eacc scan, but the Q_0 values gradually degraded after breakdown at the maximum field. Finally, strong field emission was observed at the lower field, and the maximum field was limited to about 10 MV/m by field emission. This phenomenon was observed in every cavity test. The breakdown was usually accompanied with a vacuum burst and x-ray emission. So, it was supposed that sparking might have occurred somewhere inside the cavity. After some trials,

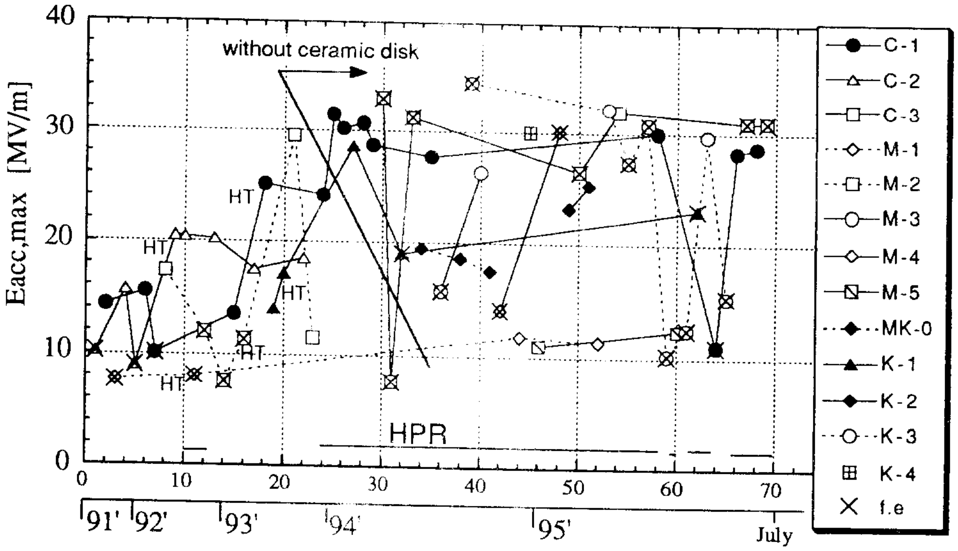

Fig. 1 History of the cavity tests on 13 single-cell cavities.

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

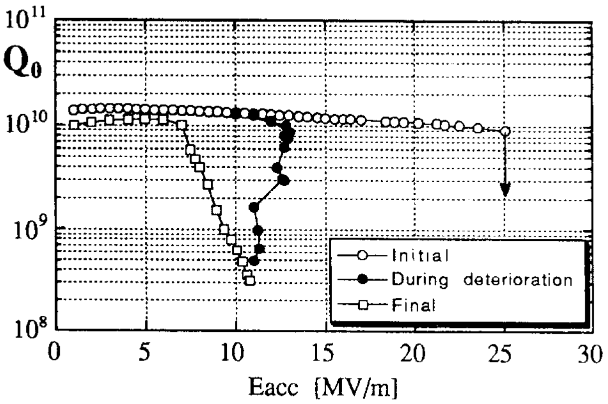

Fig. 2 Q_0-deterioration after breakdown.

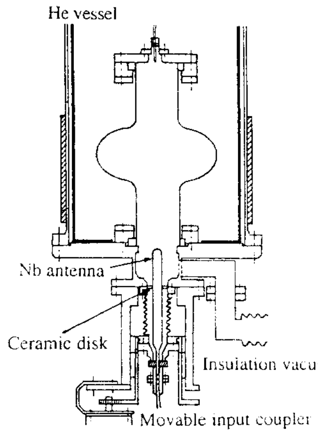

Fig. 3 A vertical cold test system.

it was found that the ceramic disk attached to the input coupler was involved in Q_0-deterioration. This ceramic disk was used not as a vacuum seal, but for supporting and centering the niobium antenna of a movable input coupler. The vertical cold test system is shown in Fig. 3. Charging by field emitted electrons or niobium dust scraped by the ceramic disk is considered to be a trigger of sparking. Therefore, the ceramic disk was removed in the beginning of 1994 as shown in Fig. 1. Q_0-deterioration was eliminated after this, and the cavity performances improved remarkably as a result.

3. Test Results on Single-cell Cavities

After eliminating Q_0-deterioration, the cavity tests were carried out systematically. Since cavity performances are governed by many factors, the reproducibility and statistics of the test results are very important in order to discuss these performances. Therefore, the cavities were prepared using a similar surface treatment based on the standard procedure in the TRISTAN cavities. Heavy first polishing of more than 160 μm and heat treatment at 760°C or 1400°C were carried out. The test results of 36 tests on 11 cavities are summarized in Fig. 4. HPR was carried out in every test. The limiting factors of the Eacc,max, like thermal quench and rf power, and an occurrence of field emission are shown in this figure. It is clear that the possibility of field emission at a low field was drastically reduced by the development of HPR, improvement of a clean environment and careful handling. However, field emission occurred in the initial tests in the M-3 and M-4 cavities. These performances were improved in the following test after an additional surface removal of 50 μm was carried out by chemical polishing. In the K-1 cavity, the Eacc,max of 29 MV/m with no field emission was achieved in the initial test, but field emission occurred in a subsequent test. An accidental surface contamination during rinsing or assembling seems to be a reason of field emission. On the other hand, the cavities made from a niobium material of RRR=100 (Heraeus), M-1 and MK-0, were limited to the relatively low quench fields of 12 MV/m and 19 MV/m, respectively. Since a temperature rise on a welding seam at the equator was observed during thermal quenching, welding imperfections are suspected to be a potential cause of thermal quench in M-1. In the M-5 cavity fabricated with a waveguide input coupler, the Q_0 values suddenly dropped to 10 MV/m due to an abnormal heating, but the location of heating was not yet identified.

Q_0 - Eacc plots on 6 single-cell cavities, which exceeded a goal required for TESLA, is shown in Fig. 5. Each cavity achieved the Eacc of 25 MV/m with a high Q_0 value of more than 5 x 10^9. Field emission was not a major problem in these tests, and the limitation of the Eacc,max was a thermal quench in each test. There were processing levels due to multipacting around 20 MV/m in some cavities, but it was processed out by a short cw rf processing.

The quench field at 1.8 K as a function of RRR value is shown in Fig. 6. The results of the cavities heat-treated at 1400°C are indicated with black circles. These cavities were tested several times after re-treatment, but the Eacc,max limited by a thermal quench did not improve. No significant difference in the attained Eacc,max has been observed between RRR = 200 (Tokyo Denkai) and RRR = 350 (Fansteel). Moreover, the effectiveness of heat treatment at 1400°C has not been seen. The Eacc,max of 35 MV/m was achieved in the RRR=200 cavity (K-3) with no heat treatment at 1400°C. A more detail discussion of the test results of the single-cell cavities is given in reference [3].

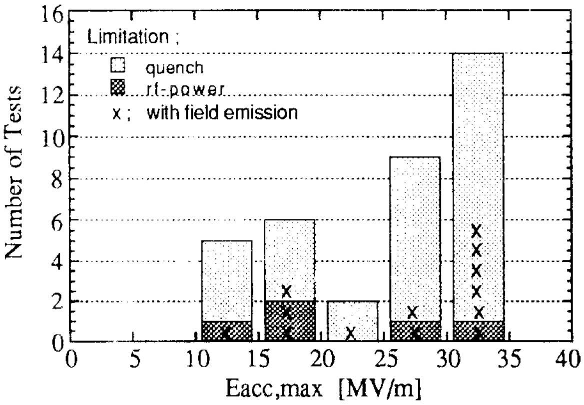

Fig. 4 Distribution of the Eacc,max after removing the ceramic disk.

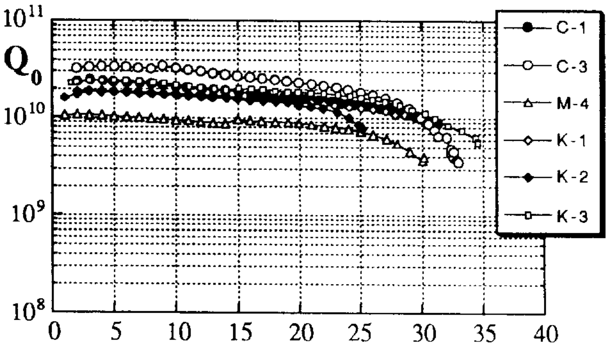

Fig.5 Q_0 - Eacc plots on 6 single-cell cavities after removing the ceramic disk.

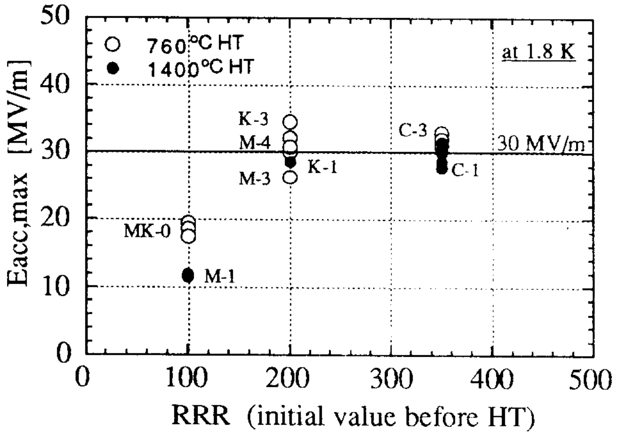

Fig. 6 RRR dependence of the Eacc,max limited by a thermal quench at 1.8 K.

4. R & D Program

4-1. Improvement of Surface Preparation Techniques

The HPR system (pressure of 85 kg/cm^2 and flow rate of 13 l/min) and MSR system (mega-sonic rinsing; frequency of 950 kHz and oscillator power of 600 W) were developed for the active removal of dust or debris on the cavity surface. The effectiveness of HPR was confirmed in the experiments in which the cavities were contaminated by disassembling or annealing. HPR with pure water (0.2 μm filter), instead of ultrapure water, was still effective for the elimination of field emission [4].

Barrel polishing with plastic tips was investigated in order to obtain a smooth surface in welding seams. In an optimized condition on niobium samples, the surface roughness of 0.7 μm and the removal speed of 13 μm/day were obtained [5].

4-2. Fabrication of Seamless Cavities

A seamless cavity has great advantages for both decreasing fabrication costs and eliminating imperfections by electron beam welding at the iris and equator. The feasibility tests for explosive forming and hydro-bulge forming were carried out using copper tubes prior to niobium ones. The preliminary results suggest that intermediate annealing is required for both methods because the expansion ratios were limited to 60 and 65 % [6].

4-3. Magnetization Measurement

Lattice imperfections like impurities or dislocations in the material can be observed by magnetization hysteresis measurements. Measurements of the magnetization were made with small niobium samples (3 x 2 x 10 in mm) using the moving-sample method. The effects of annealing, chemical polishing, titanium migration and Q-disease due to hydrogen were clearly observed in this method [7].

4-4. Test of nine-cell Cavities

Two nine-cell cavities were fabricated at CEBAF and MHI in 1992. The CEBAF cavity was limited by a thermal quench at 9 MV/m probably by defects. The MHI cavity was tested three times, but strong field emission at 10 - 12 MV/m were observed [1]. During the surface treatment, the cavities were exposed to contaminated air in contrast to that of the single-cell cavities. So, a clean room for the surface preparation was constructed, and the clean environment was improved to the same condition as that of the single-cell cavities.

5. Future Plan

Until now, our activities have concentrated on R & D of high gradient cavities. A collaboration with JAERI (Japan Atomic Energy Research Institute) to develop a superconducting proton linear accelerator for a neutron spallation source [8] has been started. A high intensity proton beam with a cw current of 10 mA will be accelerated up to 1.5 GeV by niobium cavities with a different structure depending on its β value (β = 0.43 - 0.92). Therefore, our efforts will be extended to R & D of other components which will be a good exercise for TESLA.

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