TEST RESULTS ON THE 9-CELL 1.3 GHZ SUPERCONDUCTING RF CAVITIES FOR THE TESLA TEST FACILITY LINAC

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Abstract

The design goal for the TESLA Test Facility Linac is an accelerating gradient of 15 MV/m at a quality factor of $Q = 3{\cdot}10^9$. In the linac the cavities are operated in pulsed mode (constant gradient for 800 μs with 10 Hz repetition rate). The majority of the first 17 industrially produced cavities exceeded the specification. Several cavities reached 25 MV/m at $Q > 1{\cdot}10^{10}$. Due to cleaning by high pressure water rinsing most of the cavities showed no field emission loading; the major limitation was thermal instability. In cavities with poorer performance, two types of field limitations were identified by temperature mapping and further surface analysis: tantalum impurity in the bulk niobium and defects in the equator welds. Eight cavities, equipped with main power coupler, HOM couplers and tuning system have been successfully tested in a horizontal cryostat in pulsed mode. Also here the majority of the cavities exceeded the design goal and gradients up to 25 MV/m could be achieved.

1 INTRODUCTION

TESLA (TeV Superconducting Linear Accelerator) is one of the proposed future TeV scale e^+e^- linear colliders. It differs from other projects in its choice of superconducting accelerating structures and of low frequency (1.3 GHz).

In order to prove the technical basis of TESLA the TESLA Test Facility (TTF) is under construction at DESY within the framework of an international collaboration. The aim is to show that accelerating gradients above 15 MV/m at quality factors above $3{\cdot}10^9$ are reproducibly achieved and can be maintained after assembly to the linac together with the necessary auxiliary system [1].

All together seventeen 9-cell cavities manufactured by three different companies have been tested in a vertical cryostat so far. In addition eight cavities were fully equipped with all components in a horizontal cryostat and tested. A summary and comparison of the vertical and horizontal tests are given in this paper.

The first cryomodule of the TTF Linac containing eight superconducting 9-cell cavities has been assembled. First acceleration of the beam by this module is expected in June 97 [2].

2 CAVITY TEST PROCEDURE

After delivery from industry, the cavities receive the following treatment and test procedures:

- Visual inspection and dimensional check;
- Removal of the inner damage layer by 80 μm buffered chemical polishing (BCP). This is done by a closed loop etching facility with active cooling in order to avoid heating of the acid to temperatures above 12°C.
- Removal of 10 μm from the outer surface by BCP;
- Heat treatment with titanium getter at 1400°C for 4 hours in order to raise the residual rest resistivity ratio (RRR) of the cavities from 300 to 500;
- 80 μm BCP from the inside in order to remove titanium from the superconducting surface. 30 μm BCP from outside in order to improve the Kapitza conductance.
- Field profile measurement and tuning to correct frequency;
- Final inner BCP of 20 μm;
- High pressure (100 bar) water rinsing (HPR) [3], drying in air in a class 10 clean room;
- Assembly, additional HPR, drying by pumping;
- Acceptance test in a vertical cryostat including the possibility to apply high power processing (HPP) [4];
- Field profile check;
- Welding of the He-vessel made out of titanium;
- Inner BCP 20 μm, HPR, drying in a class 10 clean room;
- Assembly of high power and HOM-couplers;
- HPR and drying by pumping;
- Assembly of the tuning mechanism and magnetic shielding;
- Test in a horizontal cryostat including high power coupler processing;
- Assembly of eight cavities in a cryomodule;

3 VERTICAL TESTS

Seventeen 9-cell cavities produced by three European companies have been tested so far in a vertical cryostat. The average gradient was 17.2 MV/m at Q values above $3{\cdot}10^9$. The main limitation of the cavities was thermal instability. Field emission could be strongly suppressed by means of careful high pressure water rinsing.

Seven cavities showed gradients above 20 MV/m. Their $Q(E)$-behaviour is shown in figure 1. Two cavities reached 25 MV/m at $Q > 10^{10}$ without any field emission loading.

In the linac the cavities are operated in the π-mode with equal gradients in all cells. By excitation of the other coupled modes a non-uniform field distribution can be achieved which allows to determine the high field performance of individual cells. In five cavities of lower gradients a single cell was identified to be responsible for the

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limitation while the other cells could be excited to much higher fields.

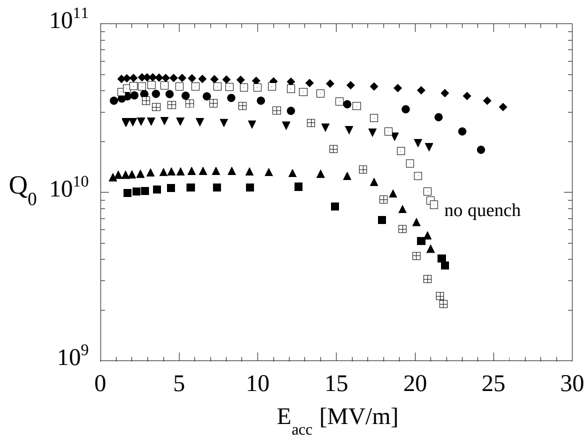

Figure 1: $Q(E)$-behaviour of TESLA 9-cell cavities which reached more than 20 MV/m. One cavity was limited by the available incident power, all others showed a thermal breakdown, some under field emission loading.

3.1 Defects in the bulk niobium

Three niobium cavities from one manufacturer, produced from the same ingot, showed quenches at gradients from 8 to 14 MV/m. They also exhibited a so called ”Q-switch”, which is a sudden drop in quality factor with increasing incident power (see figure 2). Localized areas with excessive heating were found by temperature mapping. In one cavity the defective cell was cut out and investigated with X ray fluorescence spectroscopy. A tantalum grain close to the RF surface was found. A sensitive eddy current scanning system, developed at the Bundesanstalt für Materialforschung, Berlin, was able to detect the inclusion. In the future this type of material defects will be excluded by eddy current scan of the niobium sheets. 5 % of recently produced niobium sheets had to be rejected.

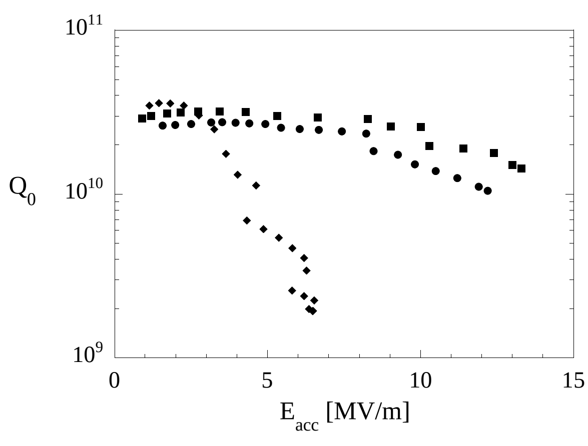

Figure 2: $Q(E)$-behaviour of 9-cell cavities which showed a ”Q-switch”. All cavities were produced by one manufacturer from the same ingot material. The Q-switches and quenches are probably caused by foreign material inclusions.

3.2 Defects in the equator welds

All cavities produced by another manufacturer exhibited a thermal breakdown in the 11 to 15 MV/m regime combined with a so called ”Q-slope”, a continuous reduction of the quality factor from approximately $3 \cdot 10^{10}$ at low gradient to about $1 \cdot 10^{10}$ near the quench field (figure 3). No field emission was observed.

Three of the cavities were investigated with temperature mapping. Several locations with field-dependent surface resistance were found in the equator welds which caused the Q-slope and also the quench. An analysis showed that the welding procedures at this company were not adequate for gradients in the 20-25 MV/m regime.

A cavity with improved welding technique has recently been fabricated by this company. The preliminary test result is shown in figure 4. A remarkable improvement is observed. The maximum gradient of 22 MV/m is not limited by quench but by the available incident power. There is no Q-slope visible up to gradients of 16 MV/m, however field emission sets in at 16 MV/m. This cavity will be high pressure water rinsed soon and retested again.

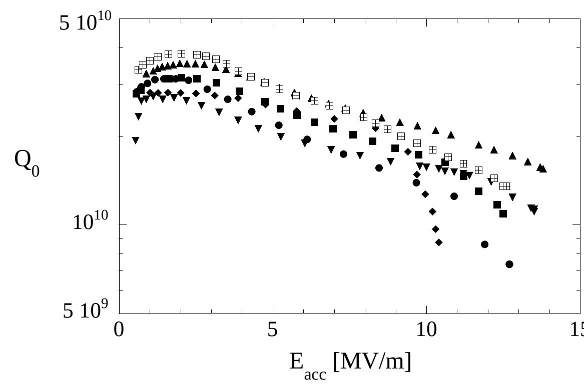

Figure 3: Cavities showing a ”Q-slope” and quench in the 11-15 MV/m regime. There was no field emission present. All cavities were produced by the same manufacturer.

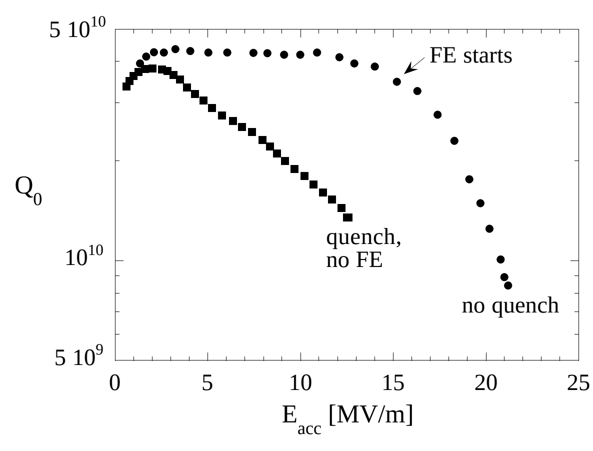

Figure 4: $Q(E)$-behaviour of a cavity produced with new welding technique. The cavity showed field emission above 16 MV/m. For comparison one of the previous cavities (figure 3) is shown.

3.3 Test in pulsed mode

A number of cavities were tested in the vertical cryostat also in the pulsed mode as foreseen in the linac operation. For this purpose the cavity was equipped with a high power coupler tunable from $Q_{ext} = 10^{10}$ (needed in cw operation) to $3{\cdot}10^6$ (needed in pulsed operation). In pulsed mode the gradient is kept constant for 800 μs at a 10 Hz repetition rate. The gradients achieved in the pulsed mode are always higher than in cw operation (figure 5).

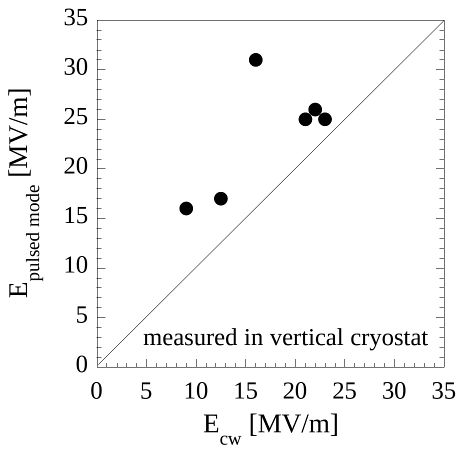

Figure 5: Comparison of cw and pulsed operation of cavities tested in the vertical cryostat.

4 HORIZONTAL TESTS

Eight cavities equipped with all auxiliary components (helium-vessel, high power coupler, HOM-couplers, tuning mechanism and magnetic shielding) were tested in a horizontal cryostat. Because of the low Q_{ext} of the high power input coupler only measurements in the pulse mode were possible.

The cavities reached an average gradient of 17.5 MV/m at $Q > 3{\cdot}10^9$ (see figure 6) compared to an average gradient of 18.6 MV/m at $Q > 3{\cdot}10^9$ in cw mode in the vertical test stand. In contrast to the vertical tests, field emission has been observed more frequently. The reason is probably particle contamination due to the more complicated assembly and to the processing of the main power coupler. The higher field emission loading is responsible for the slight degradation in performance.

Cavities showing strong field emission can be further improved by applying high power processing (HPP) [4]. For this purpose, short pulses of high instantaneous power (≈ 400 μs, up to 1 MW) are applied to destroy field emitters. The power coupler has to be carefully processed up to 1 MW, which may take several days. Due to a tight time-schedule HPP was not applied during the horizontal test. It still can be done after the installation of the cavities in the first cryomodule and in the linac.

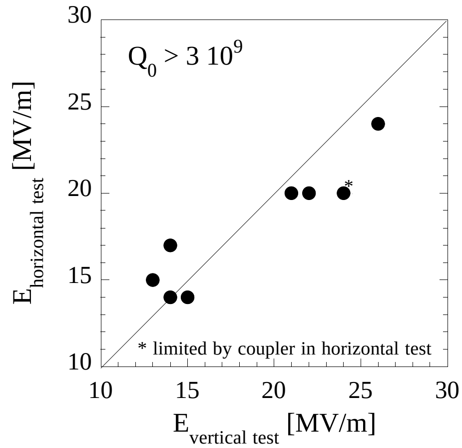

Figure 6: Comparison of the performance of cavities tested in the vertical cryostat in cw mode and in the horizontal test cryostat in the pulsed mode.

5 CONCLUSION

Most of the first TESLA 9-cell cavities for the TTF Linac exceeded the specifications of 15 MV/m at $Q = 3 \cdot 10^9$. Seven cavities reached gradients above 20 MV/m, two reached 25 MV/m with $Q > 10^{10}$.

In cavities with poorer performance, two types of limitations were found: tantalum inclusion in the bulk niobium, and imperfect equator welds.

Cures have been found for both types of imperfections. Using a dedicated eddy current scanning system defective niobium sheets will be rejected from the next cavity production. The second limitation has been overcome with a new welding technique. The first cavity built with this new welding procedure showed no quench at 22 MV/m. With better material control and better welding technique, gradients higher than 20 MV/m are expected to be routinely possible now.

In the horizontal tests, a slight reduction in gradient caused by higher field emission loading compared to the vertical test is. Work is in progress to improve the cleaning and mounting procedures prior to the horizontal test.

6 REFERENCES

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[4] J. Graber, PhD thesis, Cornell University, 1993 C. Crawford et al.: 'High gradients in linear collider superconducting accelerator cavities by high pulsed power to suppress field emission', Part. Acc. **49**, pp. 1-13, 1995