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

M. Pekeler for the TESLA Collaboration, DESY, 22603 Hamburg, Germany

Abstract

So far 25 9-cell cavities have been tested at the TESLA Test Facility. The majority of the cavities exceeded the design goal of 15 MV/m and gradients up to 29 MV/m have been reached in a vertical test cryostat. Techniques have been developed to eliminate defective niobium sheets from cavity production and to avoid performance degradation in electron beam welds. Recently cavities were limited at gradients above 20 MV/m by field emission and available RF power. 13 cavities were tested in addition in a horizontal test cryostat, the best cavity reached 33 MV/m. The performance of nine cavities installed in the linac is comparable to the vertical test results and gradients up to 25 MV/m have been achieved.

1 INTRODUCTION

In may 1994 the infrastructure at the TESLA [1] Test Facility (TTF) at DESY was ready to prepare and test superconducting cavities. At this time 2 Prototype 9-cell cavities (P1 and P2) were available. In addition 27 more cavities were ordered at 4 European companies. The goal was to use these cavities in the TTF-linac [2] [3] and show that accelerating gradients of 15 MV/m at a quality factor $Q > 3 \cdot 10^9$ are achievable.

9 cavities from this first production are operating in the TTF-linac and 8 more cavities will be installed soon. In end of 1997 26 more cavities were ordered which start to arrive now.

2 VERTICAL TEST RESULTS

The standard cavity preparation before the vertical test consists of the following steps: 80 μm removal from the inner surface by buffered chemical polishing (BCP), a 2 hours heat-treatment (HT) at 800 °C, 20 μm removal by BCP, a 4 hours HT at 1400 °C with titanium getter and additional 100 μm removal by BCP. The cavity is then rinsed with high pressure (100 bar) deionized ultrapure water.

The best test results (π-mode) are shown in table 1. It is remarkable that a lot of cavities achieve fields above 25 MV/m.

Table 1: Best results of 9-cell cavities in vertical tests. $^+$: limited by available cw RF power (no quench observed).

cavity	$E_{\rm acc}$ MV/m	Q_0 10^9	status / comment
P1	29.1$^+$	6	prototype cavity
P2	16.3	22	prototype cavity
D1	24.7	17	linac operation (module 1)
D2	21.9	4	module 1
D3	25.6	29	module 1
D4	13.5	16	module 1
D5	8.6	4	material defect
D6	13.6	2	material defect
S7	13.8	8	module 1 / weld defects
S8	12.5	12	module 1 / weld defects
S9	11.4	11	weld defects
S10	14.2	16	module 1 / weld defects
S11	13.5	13	module 1 / weld defects
S12	12.6	13	weld defects / used at FNAL
S28	24.9$^+$	5	new welding procedure
A14	6.4	11	quench at repaired weld
A15	23.0$^+$	4	preparation for module 2
C19	22.1	2	linac (capture cavity)
C21	29.3$^+$	8	preparation for module 2
C22	20.2	21	preparation for module 2
C23	25.3$^+$	8	preparation for module 2
C24	19.7$^+$	5	preparation for module 2
C25	28.4$^+$	9	preparation for module 2
C26	21.4$^+$	4	preparation for module 2
C27	26.7$^+$	8	preparation for module 2
avg.	19.2		

2.1 Performance of individual cells

By excitation of the other 8 members of the fundamental mode, it is possible to reach higher fields in individual cells of the 9-cell structure than in the π-mode. Table 2 shows the maximum fields reached in individual cells. Values up to 36 MV/m have been achieved.

2.2 Defects in the bulk niobium

Several of the cavities (P1-D6) from one manufacturer produced from the same ingot, showed very good results with gradients up to 29 MV/m. But some cavities were limited below 16 MV/m although most cells reached much higher fields (see table 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 was found close to the RF surface. A sensitive eddy current scanning system, developed at the Bundesanstalt für Materialforschung, Berlin, was able to detect the inclusion [4]. For the new cavity production such material defects will be excluded by eddy current scan of the niobium sheets.

Table 2: Highest fields reached in individual cells of the 9-cell structure. $^+$: cells limited by available cw RF power, *: values taken from π-mode measurement.

cavity	maximum fields [MV/m] in cells				
	1/9	2/8	3/7	4/6	5
P1	29^*	29^*	29^*	29^*	29^*
P2	16^*	16^*	16^*	16^*	16^*
D1	25	25	26	27	26
D2	27^+	19	29^+	27^+	31^+
D3	25^*	25^*	25^*	25^*	25^*
D4	22	26	14	30	16
D5	22^+	9	22^+	22^+	16
D6	24	25	16	28	14
S7	15	14	15	16	15
S8	15	18	13	21	16
S9	20	23	26	21	11
S10	16	21	14	14	21
S11	17	21	15	14	21
S12	13	16	13	13	16
S28	31^+	28^+	28^+	30^+	30^+
A14	18	6	18	18	14
A15	23^+	23^+	24	25^+	23^+
C19	22^*	22^*	22^*	22^*	22^*
C21	31^+	28^+	31^+	34^+	36^+
C22	28	24	28	28	20
C23	29^+	30^+	27^+	29^+	30^+
C24	23	20^+	23	23	20^+
C25	29^+	28^+	30^+	28^+	29^+
C26	24^+	25^+	25^+	25^+	26^+
C27	28^+	28^+	27	27^+	29^+

2.3 Defects in the equator weld

Six cavities (S7-S12) produced by another manufacturer showed quenches around 11 to 14 MV/m. Most cells of these cavities were limited below 16 MV/m. Three of the cavities were investigated with temperature mapping. Several cells with heating in the equator weld were found which caused the quench. An analysis showed that improper cleaning of the weld area was responsible for the bad cavity performance [5]. With improved weld parameters and weld preparation a new cavity (S28) reached 25 MV/m without quench.

During the production of one cavity (A14) from the third manufacturer a whole was blown in one equator weld. A repair was done by welding in an extra machined plug. The repair was only good for 6 MV/m, but other cells reached up to 18 MV/m. The second cavity (A15) achieved 23 MV/m.

All the cavities (C19 - C27) produced from the fourth manufacturer reached gradients above 20 MV/m, two more than 28 MV/m. Only one cavity was limited by a quench at 20 MV/m caused by a repaired whole of an equator weld.

2.4 Benefit of the 1400 °C heat-treatment

A HT of 1400 °C with titanium getter increases the RRR (residual resistivity ratio) and the thermal conductivity of the niobium. Produced from RRR 250-380 material RRR values of 700 were measured after the 1400 °C HT.

Some cavities were tested already after the intermediate 800 °C HT. The benefit of the 1400 °C HT on cavity C21 is shown in figure 1. The quench at 21 MV/m was no longer present after the 1400 °C HT even at a field of 29 MV/m. Other examples of cavity improvement are listed in table 3. A degradation after a HT of 1400 °C was never observed.

A HT of 1400 °C can cure some but certainly not all defects as is evident from the results on S7-S11 which exhibit the same RF performance as cavity S12 which was only heat-treated at 800 °C.

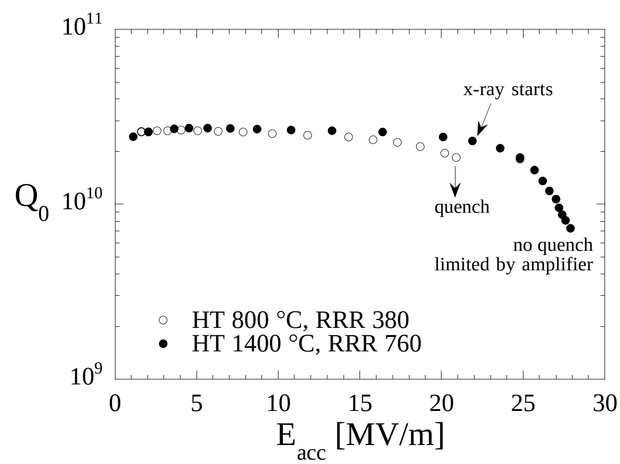

Figure 1: Improvement of cavity C21 after a 1400 °C heat-treatment.

Table 3: Improvement from heat-treatment of 1400 °C. $^+$: limited by available cw RF power (no quench observed).

cavity	gain E_{acc}	gain RRR	improved location
C21	$21 \rightarrow 31^+$	$380 \rightarrow 760$	cell 9 equator weld
C25	$25 \rightarrow 29^+$	$350 \rightarrow 690$	cell 9 equator weld
	$26 \rightarrow 29^+$	$350 \rightarrow 690$	cell 5 equator weld
C27	$24 \rightarrow 27$	$250 \rightarrow 650$	somewhere cell 3/7

3 HORIZONTAL TESTS & OPERATION OF CAVITIES IN THE TTF-LINAC

So far 13 cavities have been tested in a horizontal test cryostat, equipped with all auxiliary components like helium vessel, tuning system, main coupler and higher order modes couplers. The cavities are operated in pulsed mode with 500 μs rise time and 800 μs constant gradient time.

Figure 2 shows the comparison between vertical and horizontal tests. Some cavities show higher field emission loading in the horizontal test leading to a lower gradient, probably caused by the complicated mounting of the power coupler. A second problem is the conditioning of the main coupler. Multipacting in the coupler sometimes limits the achievable gradient.

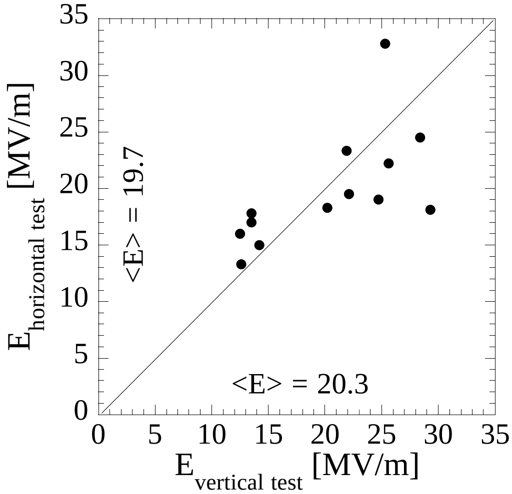

Figure 2: Comparison of horizontal (pulsed mode) and vertical (cw mode) tests.

Figure 3 shows the best horizontal test so far. The cavity C23 reached 33 MV/m with a quality factor $Q = 4 \cdot 10^9$ determined by cryogenic loss measurements. At 34 MV/m a quench occurred. In the vertical test, this cavity reached 25 MV/m limited by available RF power.

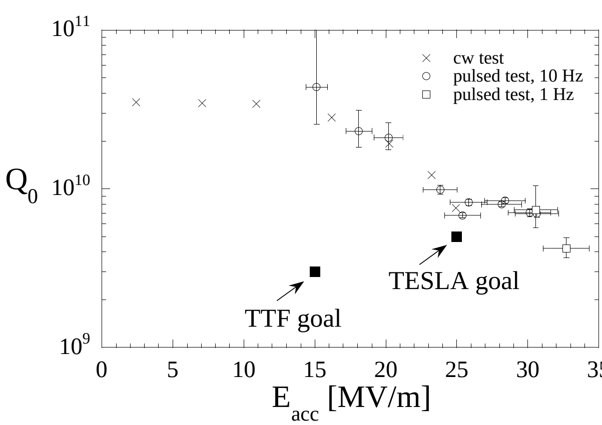

Figure 3: Horizontal test result of cavity C23 compared to vertical test.

After installation in the linac the cavities can be tested again under pulsed conditions. Here the capture cavity C19 showed a reduced performance due to field emission loading (see figure 4). The 8 cavities mounted in module 1 reached almost the same results as in the vertical tests. One cavity D2 showed a slightly higher, one cavity D3 a slightly lower gradient, caused by field emission.

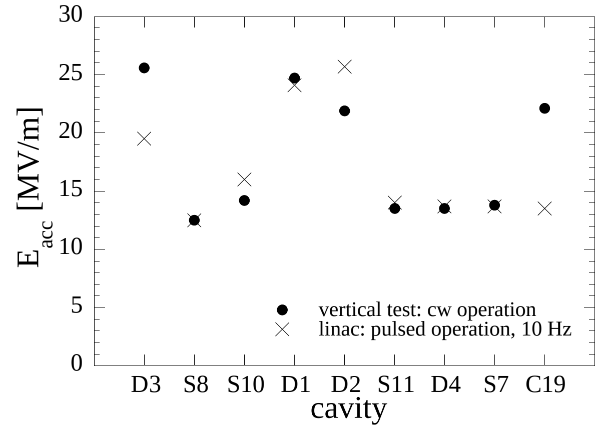

Figure 4: Performance of cavities in the linac compared to vertical test results.

4 CONCLUSIONS

The TTF cavities from the first production have been measured with an average gradient of 19.2 MV/m. All four manufacturers were able to produce cavities with gradients higher or close to 25 MV/m. In cavities with poorer performance, tantalum inclusion in the bulk niobium and imperfect equator welds have been found as limiting factors. A eddy current scanning apparatus for niobium sheets was developed and welding procedures were established which should guarantee cavities reaching routinely 25 MV/m in the future.

In the horizontal test cryostat gradients up to 33 MV/m have been achieved. Some cavities showed more field emission loading there than in the vertical test. In the Linac, the results of the cavities were comparable to the vertical test results.

Presently field emission above 20 MV/m often limits the cavity and does not allow to find the real quench limit. In order to safely reach gradients above 25 MV/m in 9-cell structures, the reduction of field emission loading is of highest importance. To preserve the high performance in the linac, some improvements in the cleaning, mounting and conditioning procedure of the power coupler are still needed.

5 REFERENCES

[1] R. Brinkmann et. al.: Conceptual Design of a 500 GeV e^+e^- Linear Collider with integrated X-ray Laser Facility, DESY 1997-048, 1997

[2] D.A. Edwards: Tesla Test Facility Linac - Design Report, TESLA 95-01, 1995

[3] S. Schreiber: The Tesla Test Facility Linac - Status Report, this conference

[4] W. Singer et. al.: Diagnostics of defects in high purity niobium, Eighth Workshop on RF Superconductivity, Abano Terme (Padova), Italy, 1997

[5] A. Brinkmann et. al.: Performance degradation in several TESLA 9-cell cavities due to weld imperfections, ibid ref. [4]