THE PERFORMANCE OF THE 1.3 GHz SUPERCONDUCTING RF CAVITIES IN THE FIRST MODULE OF THE TESLA TEST FACILITY LINAC

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Abstract

The design goal of the 1.3 GHz 9-cell superconducting RF cavities for the Tesla Test Facility (TTF) is a gradient Eacc ≥ 15 MV/m at a quality factor of Qo ≥ $3 \cdot 10^9$. The cavities are operated in pulsed mode: 0.8 ms constant gradient with 10 Hz repetition rate.

After the vertical acceptance test and prior to the assembly in the linac the cavities are tested in a horizontal cryostat fully equipped with helium vessel, high power input coupler, higher order modes coupler and tuning system. After installing module 1 the first 120 MeV beam has been delivered successfully.

We report about the measured results in vertical and horizontal tests, the processing of the superconducting cavity system in the first module and the performance of the cavity system before, during and after operating the linac.

1 INTRODUCTION

In order to prove the technical basis of TESLA[1] the TTF (Tesla Test Facility)[2] was established at DESY within the frame of an international collaboration. In May 1994 the infrastructure was ready to prepare and test superconducting cavities. Twenty-seven 9-cell cavities, manufactured by four different European companies have been processed and measured so far.

9 cavities from the first production are operating in the TTF linac and 8 more cavities are now being installed. In end of 1997 26 more cavities were ordered which are now under fabrication or final processing. Two of them have been measured already.

2 CAVITY TREATMENT

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 h heat treatment (HT) at 800 ˚C, a 4 h 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 ultra pure water. After welding the He-tank and prior to the horizontal test a 20 µm BCP and a high pressure water rinse takes place.

3 VERTICAL TEST RESULTS

The average gradient of the 27 cavities tested so far is 19.5 MV/m. The average gradient of the last 13 cavities measured is even 24.6 MV/m, 3 of them showed gradients Eacc > 28 MV/m (see Fig. 1). The main limitation now is field emission. It is remarkable, that all 4 manufacturers delivered cavities with gradients higher or close to 25 MV/m.

However at the time of selecting the capture cavity and the 8 cavities for module 1, only 4 cavities were available with gradients > 15 MV/m. 5 cavities were limited by quench below 15 MV/m in the vertical test (see table 1). The reasons for this limitation were found as foreign inclusions in the material and improper cleaning of weld area before welding[3,4]. In the future this type of defects will be excluded by eddy current scan of all niobium sheets and by the current fabrication method.

Table 1: Cavity performance during vertical and horizontal tests and after installation into the linac. The numbers are the gradients in MV/m. The 1. linac test was done before and the 2. test after 3 month of linac operation. At the vertical test the dissipated power is set to 100W in order to compare the cw measurement in the vertical test with the pulsed measurement (duty cycle 1%).

cavity	vertical test Pdiss <100W	horiz. test Pcryo <1W	linac 1. test Pcryo <1W	linac 2. test Pcryo <1W	linac 2. test Pcryo <3W
D3	25.3	21.0	15.5	19.1	19.5
S8	12.5	16.0	11.9	11.9	12.5
S10	14.2	13.4	13.2	14.7	15.9
D1	21.3	19.0	21.0	23.1	23.5
D2	17.7	23.5	23.6	24.5	25.6
S11	13.5	17.3	12.9	11.8	13.4
D4	13.3	13.5	11.5	12.4	13.5
S7	12.6	-	11.3	12.2	13.2
C19	19.6	19.0	12.7	-	-
sum	150	155*	134	142†	151†
average	16.7	17.2*	14.8	15.8†	16.8†

*: S7 test result taken from the vertical test
†: C19 test result taken from the 1. test of linac

4 HORIZONTAL TESTS

13 cavities for module 1, injectors and first for the module 2, 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 pulsed mode were

possible (500 µs rise time and 800 µs constant gradient at a repetition rate of 10 Hz)

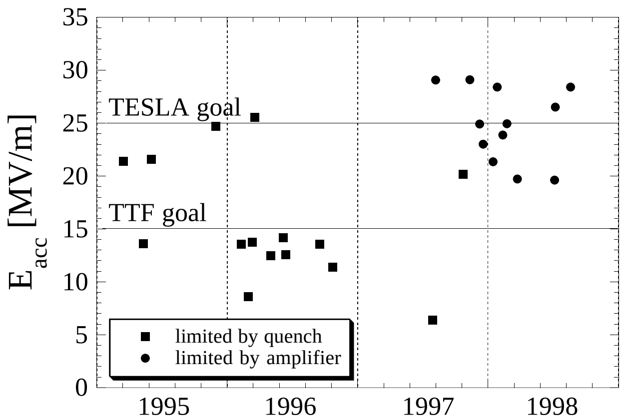

Fig. 1: Result of vertical cavity tests. The gradients below 15 MV/m before mid '97 are due to fabrication errors.

These 13 cavities reached an average gradient of 19.7 MV/m in the horizontal test compared to an average gradient of 20.3 MV/m in cw mode in the vertical test stand. In the horizontal tests, field emission has been observed higher intensities. The reason is probably particle contamination due to the more complicated assembly and the processing of the main power coupler. The higher field emission loading is responsible for the slight degradationin performance.

The performance of the cavities selected for module 1 are listed in table 1. Three cavities (D2, S8, S11) showed a higher field in the horizontal test under pulsed conditions than in the vertical cw test. This is most likely causedby the slow thermal development of the quench as compared to the rf pulse length. The other cavities sufferedfrom higher field emission or stayed constant.

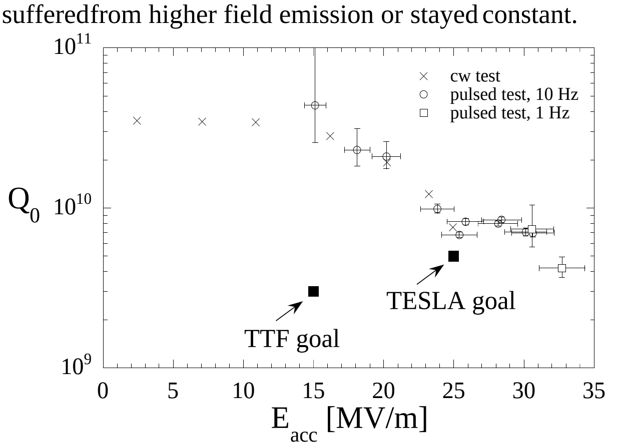

Fig. 2: The best horizontal test so far. The Q values during the pulse tests are calculated from the cryogenic losses. The cw measurement from the vertical test is given for comparison.

The best cavity tested so far in the horizontal test cryostat reached33 MV/m with a quality factor $Q = 4 \cdot 10^9$ (Fig. 2). At 34 MV/m a quench occurred. In the vertical test, this cavity reached25 MV/m, limited by available power.

Cavities showing strong field emission can be further improved by applying HPP[5]. For this purpose, short pulses of high instantaneous power (≤500 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 always applied during thehorizontal test.

5 PROCESSING OF THE MODULE 1

5.1 High power input coupler

The two types (Fermilab and DESY design) of high power couplers[6] consist each of two RF vacuum windows. The coaxial window near thecavity at 70 K and the room temperature window in front of the wave-guide (Fermilab) or as a part of the wave-guide to coax transition (DESY) outside the cryostat. The coupler vacuum of all eight couplers on the module is connected and pumped bya common ion getter pump.

All 8 cavities in module 1 are driven by one 5 MW klystron. A linear RF distribution system is branching off identical amount of power for each cavity by directional couplers.

5.2 Processing couplers and cavities

The TESLA design parameterscall for a transfer of 206 kW peak RF power per cavity to the beam with a pulse length of 1.3 ms and a repetition rate of 5 Hz. In addition it is also foreseen to apply HPP to the cavities in situ which requires1 MW at a maximum pulse length of 500 µs and at a repetition rate ≤ 1 Hz. Therefor the couplers have to be conditionedto this limits.

The coupler processing procedureat TTF starts with the cavity and coupler at room temperature. Therefor gases released by RF stimulated desorption can be pumped away. In the beginning of the conditioning the cavity is off resonance. The first power rise (dependent from the vacuum pressure and e^- and light in the vacuum) is done with a pulse length of 20 µs, then the pulse length is doubled for the next power rise and so forth. At the full pulse length the power is sweeped for some hours. After this the cavity and coupler are cooled down and the same processing procedureis carriedout again. The last part of processing is done with the cavities on resonance.

5.1. Processing results on module 1

Due to limited time the processing of couplers in module 1 was restricted to 200 kW and 600 µs. The processing of the coupler on the module at room temperature was done at two couplers at a time in order to distinguish the vacuum reactions in the common coupler vacuum. It was always observed, that initially it is possible to rise the power very quickly without being limited by outgassing, electron signals or light. After a sudden burst of outgassing on the coupler side of the cold window at a typical power level of 50 - 100 kW many hours are needed to once again reach the earlier achieved power level. Once the maximum power of 200 kW is reached for the shortest pulse length the power rises for longer pulses are straight forward. After about 48 to 72 h only one multipacting level at 125 kW is visible at the charged particle detectors. But the signals are smaller by a factor of 10 compared to the first processing hours. A second multipacting level at 65 kW is processed away.

When the module was cooled down to the operating temperature of 1.8 K the same processing procedure took place. All multipacting levels were processed after 30 h. The temperatures of the Fermilab cold window increased due to dynamic losses by about 5 K. Due to a fabrication failure during brazing metallization of the cold DESY windows occurred. This causes a much stronger temperature rise of about 100 K which does not effect the coupler behavior but creates higher losses at the 70 K shield circuit of the module.

When the cavities are on resonance the field distribution in the coupler differs from the off resonance full reflection condition. An additional processing is necessary. After only a few (1-5) more hours the couplers were fully operational without limiting the cavities. No interlock events were observed up to the TTF operating power of 125 kW during the first 30 days of operation time. After a few days power off time no new processing was needed to operate the module again.

6 OPERATION OF THE CAVITIES IN THE LINAC

After installation in the linac the cavities were measured again individually under pulsed conditions. Here the capture cavity C19 showed a reduced performance due to field emission loading (Tab. 1). The 8 cavities mounted in the 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.

Operating all cavities with one klystron and a uniform power distribution the module performance is limited by the worst cavity. Therefor the quench of cavity S7 limits the maximum gradient of the module 1 to 12 MV/m at the full pulse length of 800 µs flat top and 10 Hz repetition rate. For shorter RF pulses of 300 µs rise time and 100 µs flat top at 2 Hz repetition rate acceleration gradients of 16.7 MV/m were obtained.

7 CAVITIES FOR MODULE 2

In Fig. 3 the vertical test results of the 8 cavities forseen for the module 2 are shown. The module 2 will be installed in the linac by end of September '98. The expected average gradient for this module is ≥20 MV/m.

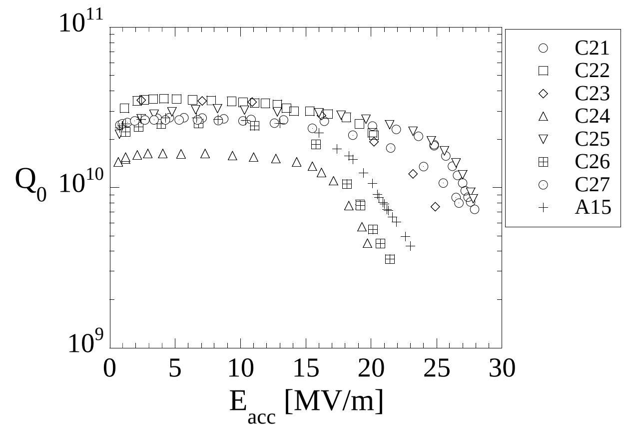

Fig. 3: Vertical test results of the 8 cavities selected for module 2.

8 CONCLUSIONS

Gradients well above 20 MV/m have been demonstratedwith 9-cell TTF cavities. Excluding only the cavities with a well identifiedfabrication error, the average gradient of 13 cavities is 24.6 MV/m.

The highest gradient in the horizontal cryostat with a fully equippedcavity was 33 MV/m.

The main limitation is field emission, indicating the high standardof niobium quality and fabrication methods. Further progress in gradient can be expectedby improving cleanliness during final treatment and assembly.

The first beam of 8 mA has been successfully accelerated. The average gradient of the first 8 cavity module is limited by one of the above mentioned cavity. Further improvement of the gradient is possible by optimizing the RF distribution**.**

A slight reduction in gradient from horizontal test to module operation was observedand is causedby high field emission loading. It shows that improvements in clean assembly and coupler handling is still necessary.

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