Vertical and horizontal cavity test results in comparison with performance in the TTF Linac

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ABSTRACT

The design goal of the 9 cell superconducting RF cavities for the TESLA test facility (TTF) linac [1] is an accelerating field of 15 MV/m at a quality factor of 3 10^9. Up to now, nine cavities are operating in the linac. One cavity (C19) is used to capture the electron bunches from the gun, eight cavities are mounted in the first cryomodule which started operation in summer 1997. The cavities were first tested in a vertical cryostat. After this they were equipped with all auxiliary components like main-power and higher-order-mode couplers, helium tank, tuning system and magnetic shielding and tested in a horizontal test cryostat. After installation in the linac the individual performance of the cavities was checked. After almost 3 months beam time, the individual performance of the cavities was checked again. No degradation of cavity performance due to the linac operation was observed. Actually some cavities improved.

1. MEASUREMENT PRINCIPLES

In the vertical test, the cavities are operated in cw mode. In the horizontal test and in the linac the cavities are equipped with the main power coupler and feeded with 1.3 ms long klystron pulses at a repetition rate of 10 Hz. The cavity field is allowed to rise for 500 µs and then kept constant for the remaining 800 µs. The cavity Q is determined by assuming that the dissipated power of the cavity is the same as the cryogenic load into the helium bath. With the horizontal test cryostat [2] a measurement of the cryogenic load within an error of 30 mW is possible. In the linac the error is in the order of 50 mW. The duty cycle at 10 Hz repetition rate (500 µs rise time, 800 µs constant gradient) is approximately 1 %. Gradients with losses in pulsed mode of 1 W have to be compared to fields with a dissipated power of 100 W in cw operation. There might be some discrepancy between dissipated power and cryogenic losses in case of heavy field emission loading. The helium vessel only surrounds the cells and not the beamtubes of the cavity. Emitted electrons leaving the cavity through the beam tube do not deposit their energy in the helium.

2. VERTICAL TEST RESULTS

The first 9 cavities used for the TTF linac can be devided into 2 families: mediocre cavities and good cavities. The mediocre cavities D4, S7, S8, S10 and S11 reached accelerating gradients in the 12 to 14 MV/m regime without field emission loading but limited by quench. It is known that the cavities S7, S8, S10 and S11 suffer from defects in the equator weld [3]. There is a suspicion that D4 has a defect in the bulk of niobium. The good cavities C19, D1, D2 and D3 reached gradients between 18 and 25 MV/m. They were also limited by quench but some (C19 and D1) showed field emission (see table 1).

3. HORIZONTAL TEST RESULTS

All cavities except S7 were tested in the horizontal test cryostat. After the helium vessel welding, 20 µm were removed from the inner surface by buffered chemical polishing. A part of the test is conditioning of the high power input coupler. This is done first with the cavities off resonance. But also on resonance the coupler has to be conditioned. By doing so, one automatically applies high power processing HPP [4] to the cavities. As can be seen in table 1 the average gradient slightly improved between vertical and horizontal test. The mediocre cavities performed very well in the horizontal test. Cavity D2 remarkably improved from 18 MV/m to 23 MV/m. The best cavity in vertical test, D3, degraded from 25 MV/m to 21 MV/m. Heavy field emission was present during the horizontal test of this cavity. A comparison between vertical and horizontal test is given in Fig. 1.

4. PERFORMANCE CHECK IN THE LINAC

Between the horizontal test and the installation in the linac the cavities were only vented with argon, except cavity D3 and S10 which were high pressure water rinsed [5] again.

4.1. First check at the beginning of the linac operation

As can be seen in table 1 and Fig. 2, the performance of the mediocre cavities (D4, S8, S10 and S11) after installation in the linac is comparable to the results obtained in the vertical test. The performance of cavity D2 is the same as in the horizontal test, much better as in the vertical test. D3 and C19 showed heavy field emission loading in the linac. The performance of D3 went down to 15.5 MV/m. The cavity C19 degraded from 19 MV/m during horizontal test to 13 MV/m.

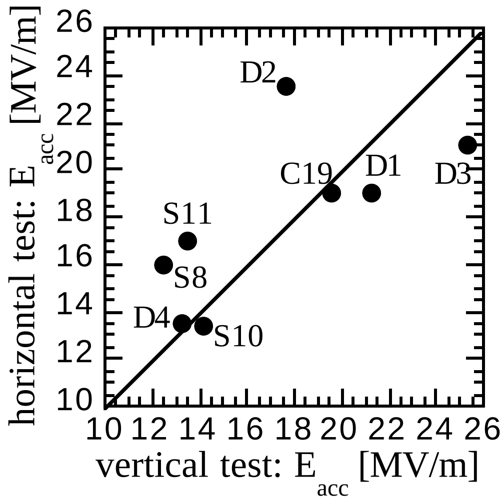

Fig. 1: Performance of the cavities in vertical and horizontal test.

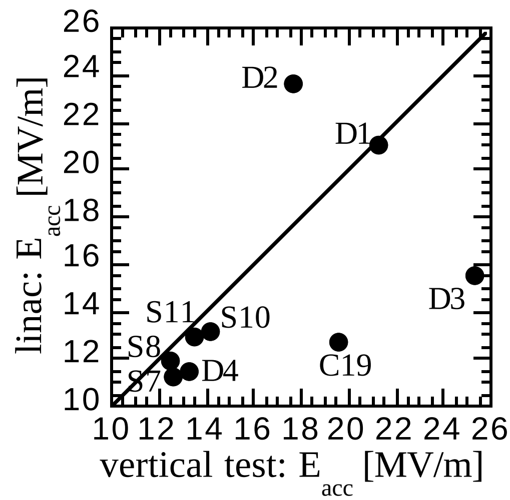

Fig. 2: Performance of the cavities after installation to the linac compared to the vertical test results.

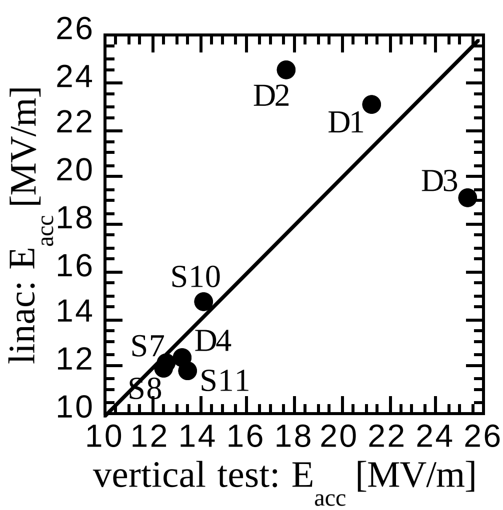

Fig. 3: Performance of the cavities after 3 months linac operation compared to the vertical test results.

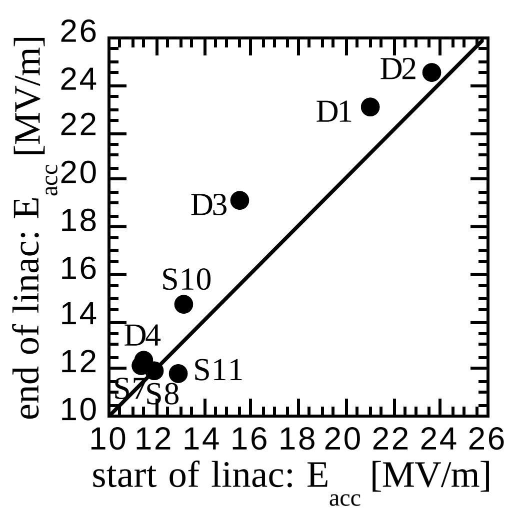

Fig. :4: Comparison of the cavity results obtained just after installation and after 3 months linac operation.

4.2. Second check at the end of the linac operation

In order to get an idea of the long time stability of the cavities when operated in the linac, the cavities (except C19) were tested again after almost 3 months of linac operation. The cavity performance increased, especially for the cavities with heavy field emission (see table 1, Fig. 3).

Cavity D1 improved to 23 MV/m, cavity D3 to 19 MV/m and cavity D2 reached even 25 MV/m at the end of the linac run. During the operation of the linac sometimes a sudden decay (faster than 1 µs) of the transmitted power was observed. This is typical for a processing event of a field emitter. These processing events are lowering the field emission loading and therefor probably responsible for the improvement of the cavity performance. Fig. 4 compares the results of the two cavity measurements in the linac.

There is still hope to increase even more the performance of the field emission loaded cavities. HPP was only performed up to 200-400 kW incident power, but can be done in principle up to 1 MW. We hope that this can be made during the next linac run in may 1998.

cavity	**vert. test** E [MV/m] Pdiss < 100 W	**hor. test** E [MV/m] Pcryo < 1 W	**linac 1** E [MV/m] Pcryo < 1 W	**linac 2** E [MV/m] Pcryo < 1 W	**linac 2** E [MV/m] Pcryo < 3 W
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	not meas.	11.3	12.2	13.2
C19	19.6*	19.0	12.7*	not meas.	not meas.
sum	**150**	**155†**	**134**	**142~**	**151~**
average	**16.7**	**17.2†**	**14.8**	**15.8~**	**16.8~**

*: cavity shows field emission loading during measurement
†: for the sum and average calculation the result from the vertical test is used for S7.
~: for the sum and average calculation the results from the first linac measurement are used for C19.

Table 1: Summary of cavity performance during vertical test, horizontal test and the two tests after installation into the linac. The test at the beginning of the linac is called linac1-test, the test after 3 months linac operation is called linac2-test. Because the cavities are operated in horizontal test and in the linac at a duty cycle of 1 %, gradients which lead to a cryogenic load of the cavities of less than 1 W are compared to gradients with a dissipated power of less than 100 W during vertical test. As a maximum usable gradient in the linac, the fields are shown for the linac2-test, where the cavities contribute a cryogenic load of 3 W each.

5. CONCLUSIONS

After mounting to the vertical test cryostat, the horizontal test cryostat and to the linac the majority of the cavities maintained their performance. Two cavities with high gradients degraded when mounted to the linac caused by heavy field emission loading. One cavity showed a much better performance under pulsed conditions than under cw operation.

The actual performance of the cavities after 3 months linac operation is comparable to the vertical test results. If one operates the cavities with a maximum allowed cryogenic load of 3 W, all cavities except D3 and C19 are showing a better result in the linac as in the vertical test. The cavities D3 and C19 still show heavy field emission. Cavity D2 works much better in the linac as during the vertical test.

It has been shown that high gradients can be maintained in superconducting multicell structures in horizontal tests and after mounting to the accelerator. The performance did not degrade but improved slightly with the linac operation.

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