OPERATING EXPERIENCE WITH SUPERCONDUCTING CAVITIES AT THE TESLA TEST FACILITY

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Abstract

A description of the TESLA Test Facility [1], which has been set up at DESY by the TeV Energy Superconducting Accelerator (TESLA) [2] collaboration, will be given as it is now after five years of installation and operation. The experience with the first three modules, each containing 8 superconducting 9-cell cavities, installed and operated in the TTF-linac will be described. The measurements in the vertical and horizontal cryostats as well as in the modules will be compared. Recent results of the operation at the TESLA design current, macropulses of 800 µsec with bunches of 3.2 nC at a rate of 2.25 MHz are given. New measurement results of the higher order modes (HOM) will be presented. The operation and optimisation of the TTF Free Electron Laser (TTF-FEL) will also be covered in this paper.

1 INTRODUCTION

To demonstrate the visibility of TESLA the TESLA Test Facility (TTF) at DESY was build. It includes the infrastructure for the chemical processing, clean room assembling and vertical and horizontal testing of the superconducting 9-cell cavities as earlier described in [3]. It has to be demonstrated that the high gradients achieved in the cavity tests can be maintained after assembling of the auxiliary systems and into the linac tunnel also in the TTF-linac under operating conditions. The performance of the modules assembled with 8 cavities each has to be demonstrated with beam as well as the SASE (Self Amplifying Spontaneous Emission) effect has to be demonstrated.

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2 WHAT WAS DONE AT THE TTF-LINAC SINCE THE LAST SRF WORKSHOP

Jun. - July 1999

- After warm up of the module 1, the leak in the beam flange connection was located. Module 1 was exchanged by module 3 where all cavities have the new modified flange design consisting of NbTi flanges instead of soft Nb lips as a sealing surface. The principle layout of the TTF-linac is shown in Fig. 1.
- Coupler and cavities were conditioned up to 16 MV/m (100 kW).

Aug. - Sept. 1999

- Beam operation at 16 MV/m.
- Commissioning of the undulators.

Oct. - Dec. 1999

- Coupler and cavity commissioning to the maximum gradient (see section 4)
- Measurement of the gradient and cryogenic losses of individual cavities in the modules 2 and 3 (see section 4)

Jan. - Jun. 2000

- First SASE and SASE gain improvement.

Jul. - Nov. 2000

- Gun conditioning.

Dec. 2000

- Installation of the beam loss safety systems as a requirement for the full TESLA pulse operation.

Jan. 2001

- The full TESLA pulse was accelerated (see section 3)

Jan. - March 2001

- HOM measurements with beam (see section 6).

April 2001

- Improvement of SASE gain.
- Surface roughness wake field measurements for the undulator beampipe [4].
- SASE user experiments.

May 2001

- Inner inspection of the gun and coupler.
- Exchange of the gun coupler window.

Since Jun. 2001

- SASE user experiments.
- Improvement of SASE gain.

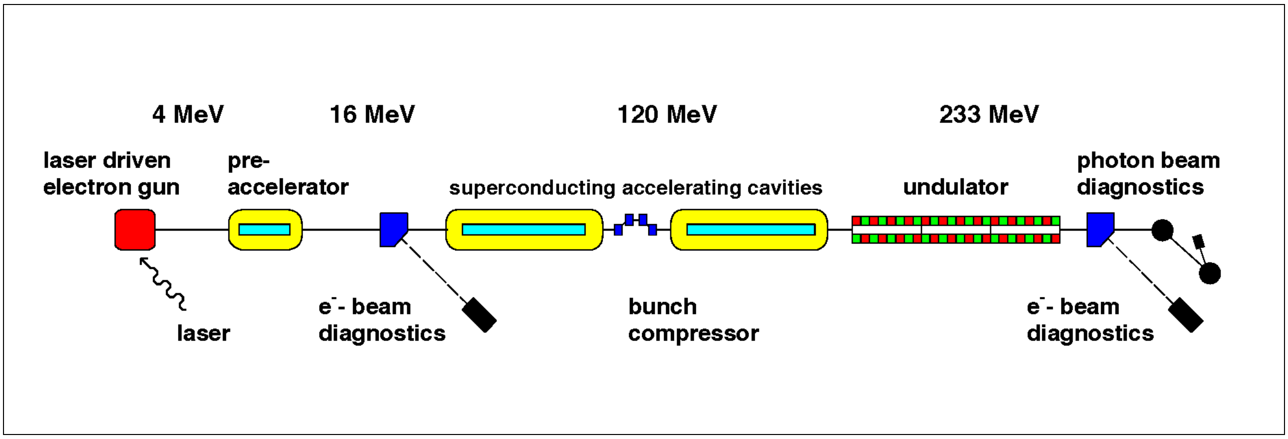

Figure 1: The schematic layout of the TTF-linac at its present status

3 MODULE OPERATION

Two accelerating modules are installed in the TTF-linac and have been operated for more than 9000 hours so far. The detailed operating times are shown in the Table 1.

Table 1: Operating times of the Cavities in the TTF-linac

Operating	gradient [MV/m]	RF pulse length [µsec]	repetition rate [Hz]	operating time [hours]
low gradient	15 - 17	400	1	4500
	15 - 17	800	1	4500
high gradient	22	800	1	>100
TESLA macro bunch*	15 - 17	800	1	>2.5

* bunch charge 3.2 nC, 1800 bunches

The TESLA design bunch charge is 3.2 nC with a bunch spacing of 444 nsec in a macro pulse of 800 µsec length. At the TTF-linac it has been shown that a beam of this structure can be accelerated [2]. The achieved energy stability was well in the requirements (see Fig 2).

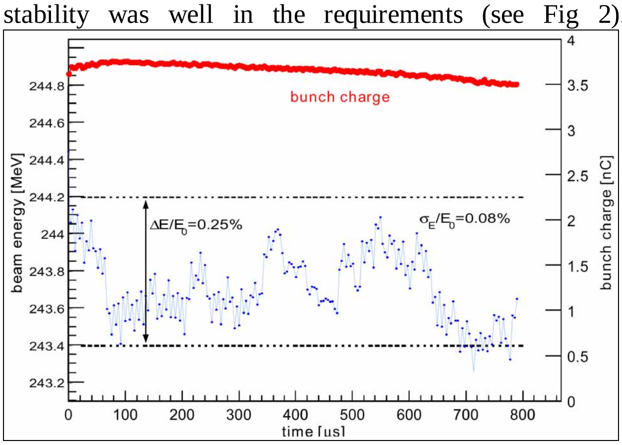

Figure 2: Energy and charge stability measured at long macropulses in the TTF-linac

The permanent magnets of the undulators are very sensitive to radiation damage (tolerable dose <10^5 Gy). An interlock system monitoring the beam losses along the linac was installed. In case of to high beam losses it switch off the beam within 3 µsec to protect the linac components.

4 CAVITY MEASUREMENTS

After installation in the tunnel all cavities of module 3 have been measured individually while the module 2 cavities are measured as a whole. The maximum average gradient of the module 2 is 20 MV/m. The main cryogenic losses of module 2 are due to a strong degradation of the 8th cavity after installation. Without cavity #8 the quality factor (Qo) of this module is well above 10^{10} (see Fig. 3).

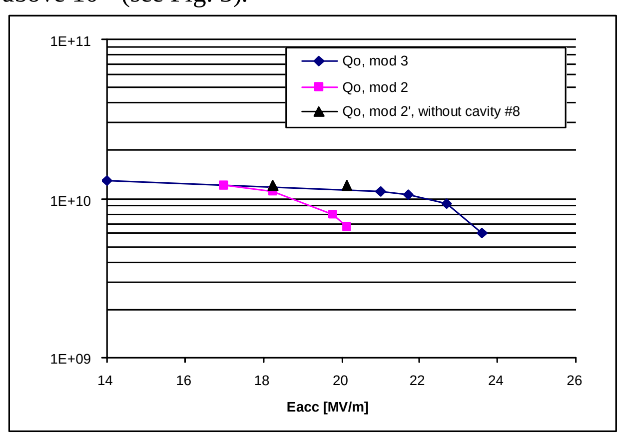

Figure 3: The quality factor vs. the average gradient of the modules 2 and 3 is shown. The cavities were operated at an 800 µsec long flat top pulse and a repetition rate of 10 Hz. The second measurement of module 2 was done with the cavity #8 detuned.

Also in the module 3 one end cavity is degraded after assembling to the linac. By operating the outer cavities at a reduced gradient the maximum average accelerating field of all 8 cavities in module 3 exceeds 23 MV/m at a Q value of $6*10^9$ (see Fig. 3). For stable operating at a

$Q=1*10^{10}$ the gradient is 22 MV/m. The individual measurement results are shown in Fig. 4.

All cavities for module 4 and 5 passed the vertical tests and led to an expected average gradient well above 25 MV/m.

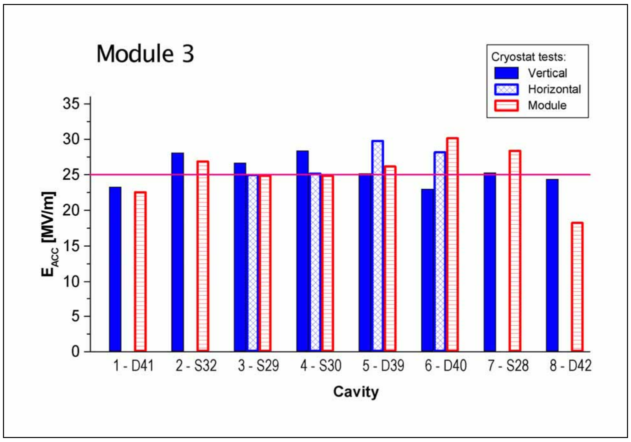

Figure 4: Individual measurements of the module 3 cavities.

The cavities of module 4 are also measured in a horizontal test cryostat under pulsed conditions. At this measurements the cavities are fully assembled with their auxiliary components like helium tank, high power coupler, HOM coupler and tuning. The time constant of the thermal break down might be longer than the pulse length. This would explain that the fields under pulsed conditions in respect to the CW measurements are often higher. The average pulsed gradient of the module 4 cavities is 32 MV/m (see Fig 5).

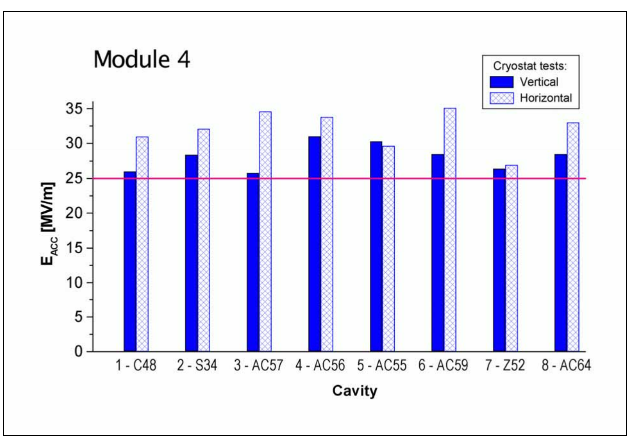

Figure 5: Individual measurements of the module 4 cavities. The average pulsed accelerating gradient is 32 MV/m

5 COUPLER OPERATION

Most of the operating time of the TTF-linac was in favour of SASE experiments. Therefore the forward power per coupler was about 100 kW. At this low power level no activities or limitations were seen in the couplers. Going to power levels above 180 kW without additional conditioning, one coupler of module 2 showed high signals on the e^- detector at the end of the pulse. Doe to the pulsed cavity operation the reflected power has the highest values at the beginning and at the end of the pulse (see Fig. 6).

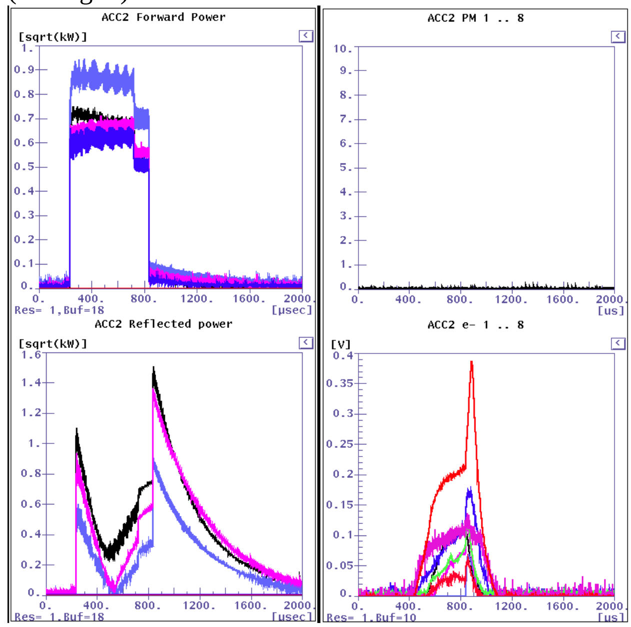

Figure 6: The left upper and lower graphs show the forward and reflected power in arbitrary units for 8 cavities in module 2 at one pulse length. Notice the high power at the end of the reflected signal. On the right side the photo multiplier signals (upper) and the e^- signals are shown in volts. Clear one can see the big spike in the e^- signal at the end of the pulse.

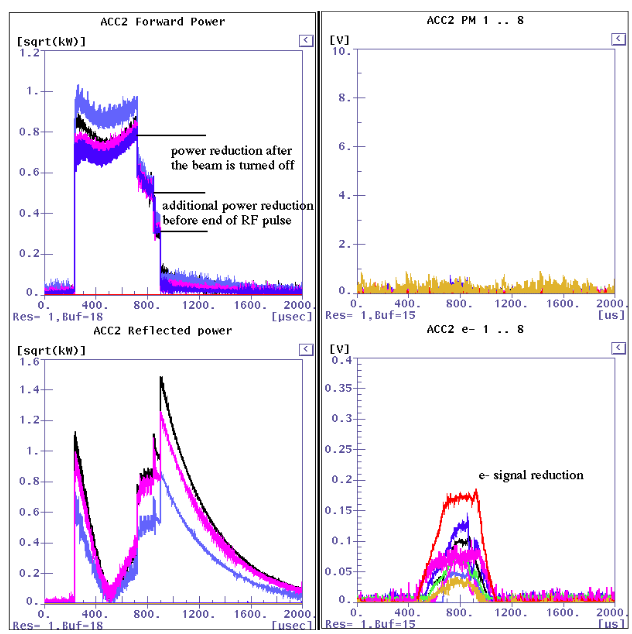

Figure 7: Shown are the same signals than in Fig. 6. But the forward power is switched of in two steps instead of one (left upper. This reduced the e^- signal substantially (lower right).

The first reflected power peak together with the forward power forms a standing wave (SW) pattern (with low field regions). The second peak is a poor travelling wave (TW) and has high field all along the coupler line. In order to reduce the high TW power after the end of the RF pulse we reduced the forward power stepwise instead of an immediate switch off. This reduced the e^- activities in the coupler substantially (Fig. 7).

Module 3 is equipped with TTF2 [5] couplers where a DC bias of the inner conductor is foreseen in order to suppress the multipacting. These couplers have been operated up to power levels above 200 kW without any sign of unwanted activities in the coupler.

6 HIGHER ORDER MODES MEASUREMENTS

A first experiment in 1998 [6] showed a dipole mode (≈2.6 GHz) with a loaded $Q > 10^5$. In early 2001 a second experiment took place to investigate the dipole modes of the first 6 passbands. The principle measurement can be described as follows: A modulation of the beam charge results in new sidebands in the frequency domain of the bunch spectrum. Changing the modulation frequency allows an excitation scan of the HOM resonances. An exited HOM will deflect the beam, which can be measured by a BPM downstream the module. If the modulation of the beam is switched off before the end of the macro pulse, the loaded Q of the HOM can be measured by the decay time of the deflection [7].

The measurement showed that some of the modes are not sufficiently damped (Qext≈few $*10^6$). The damping of the 3rd passband (dipole at 2.58 GHz with standing wave pattern in the cavity interconnection) should be increased to keep the beam break up limit independent from production tolerances. This can be done if the angular position of the HOM couplers will be properly chosen [8].

7 SASE OPERATION

After installation of the undulators the first SASE was seen at the 22nd February 2000 with a gain of $3*10^3$ [9]. Up to August 2001 the gain was improved to 10^6. During this workshop saturation was reached at a gain of 10^7. This corresponds to a peak FEL radiation brilliance of 10^{29} Phot./(sec*mrad²*mm²*0.1%bandw). Due to the operation with 20 bunches at 1 Hz repetition rate instead of the designed 10^4 bunches at 5 Hz this corresponds to an average FEL radiation brilliance of 10^{18} Phot./(sec*mrad²*mm²*0.1%bandw) [10].

8 CONCLUSION AND OUTLOOK

It has been shown that the cavities and auxiliary systems produced by industry and processed in the Tesla Test Facility have reached a level to fulfil the TESLA 500 specification. The acceleration of a TESLA type macro pulse was demonstrated. The HOM's are studied and understood.

Cavities and couplers for 6 modules are at DESY. The Modules will be installed in the TTF-FEL2 by end of 2002. One of the modules will be assembled with electro polished cavities in March 2002. Two additional modules have to be build as spares. The Niobium material, the cavities and auxiliary systems will be ordered this year. A 'TESLA-Type' module will be build and tested in TTF in 2004.

ACKNOWLEDGEMENTS

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