EXPERIENCE WITH THE TTF

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Abstract

The TESLA Test Facility in its second phase (TTF) serves two main purposes: It is a testbed for the superconducting RF technology for the International Linear Collider [1] as well as a user facility providing a VUV-FEL beam for experiments using synchrotron light [2]. The paper will review the progress on the superconducting RF technology. This includes tests on individual cavities as well as full accelerating modules. First experiences with the setup of TTF will be presented.

OVERVIEW ON THE TESLA TEST FACILITY

During the last decade the TTF accelerator was set up by the TESLA Collaboration in order to improve the superconducting accelerator technology [3]. This includes especially tests of full accelerator modules including dark current measurements. In parallel to this, a proof of principle experiment for SASE FEL physics in the ultraviolet was carried out. First user experiments validated the scientific use of such a facility. Since fall 2003, the test facility was extended by adding more accelerator modules as well as by increasing the undulator length. In its final configuration the facility will deliver photon beams of high brilliance at wavelengths down to 6 nm. User operation as well as further SASE FEL studies will support the final design of the European XFEL.

Layout of the TESLA Test Facility

TTF includes basically all the subsections and components of the proposed XFEL (see also Fig. 1):

- An RF photoinjector producing high brightness electron beams with µm emittance (normalized) at kA peak currents.
- A superconducting booster accelerator section to get ultra-relativistic electron beam energies above 100 MeV allowing for a strong suppression of Coulomb forces in the space charge dominated electron beam transport.
- A longitudinal bunch compression enlarging the peak current in order to get saturation of the SASE process within an undulator of reasonable length (typically 30 m).
- The acceleration with superconducting accelerator modules to the finally needed beam energy that determines the wavelength of the produced SASE radiation.
- Photon beam transport and diagnostics at short wavelength of 6nm.

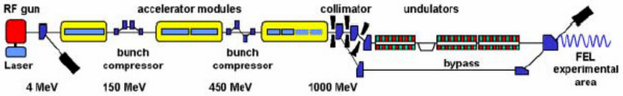

Figure 1: Layout of the Tesla Test Facility

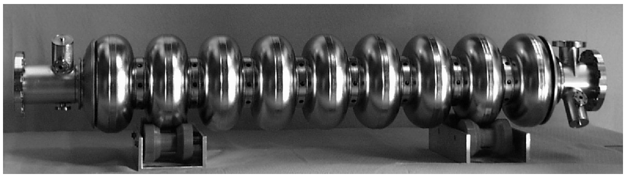

Figure 2: A TESLA niobium 9-cell cavity. The length of a cavity is about 1m.

FROM CAVITY TO CRYOMODULE

For superconducting cavities like the ones used in TTF (Fig.2) at very high electric and magnetic surface fields great care has to be taken during manufacturing and preparation for beam acceleration. For example, the preparation and assembly in clean rooms and ultra-pure water supplies for rinsing the surfaces are a must [4].

The assembly of 8 cavities equipped the cold part of the high power RF coupler and the quadrupole package (the so-called string) inside a class 10 clean room has been continuously improved. Especially, tight quality control measures were introduced. They consist for example of monitoring of water quality and detailed particle counts during assembly. These procedures are now documented with an Engineering Data Management System alongside with all RF tests of the cavities being documented in cavity database.

When the string leaves the clean room after its final leak check, the assembly of the cryomodule is done (Fig.3 and Fig.4). Amongst other things frequency tuners, RF cables and thermal shields are assembled. To date 9 string assemblies were done. The process has been continuously improved and detailed procedures are available.

The information has been evaluated in industrial studies for the cost estimate in the TESLA Technical Design Report. Currently, a new study is being launched for the European XFEL to further facilitate the industrialisation of the 120 modules for this project.

The modules for the XFEL will slightly differ from the TTF modules. The longitudinal position of the cavity will be adjusted to exactly match multiples of half the RF wavelength (λ=230.6mm). The adjustment needed is in the order of a few millimetres for each cavity. In addition, the quadrupole package will be modified to match XFEL requirements. Furthermore a broadband HOM absorber will be introduced.

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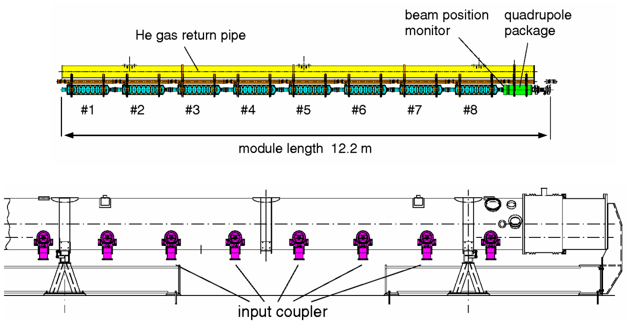

Figure 3: Layout of a TTF Accelerator module

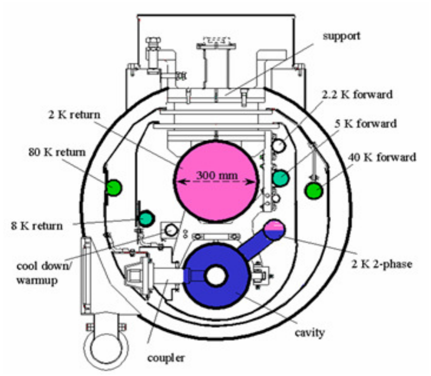

Figure 4: Cross-section of a TTF module. The last generation of cryostat design is shown.

OPERATIONAL EXPERIENCE WITH ACCELERATING MODULES

Several cooldown-warmup cycles have been done with the accelerator modules. The static heat losses are as expected.

In the latest type of cryostat the longitudinal movement of the cavity (and the coupler) during cooldown has been reduced to about 1.5 mm by means of an invar rod. In the old design the movement was up to 15mm which has caused significant problems for the coupler assembly. The alignment of the coupler during modules assembly is simplified in the last type of cryostat.

So far, all the cryostats assembled, were equipped with cavities treated with chemical etching (with one exception–see below). In the last two modules the average operating gradients were 23.5 and 25 MV/m with acceptable cryogenic losses. 11 out of the 16 cavities in those modules can perform close to 30 MV/m.

In addition to the cavity cryogenic losses the dark current of these modules has been measured (see Fig.5). During this measurement the RF feedback was not available. The detuning due to Lorentz forces can be seen in the cavity gradients. Only one cavity (#6 in the last accelerator module) produced a mentionable dark current at 25 MV/m (Fig. 5 top). The dark current in this cavity reduced with time from 10 µA (first measurement in 2003) to 250 nA (most recent measurement in fall 2004). This behaviour might be due to processing of the field emitter during operation. All other cavities produced an integrated dark current of about 25 nA at 25 MV/m average gradient (Fig. 5 bottom). The TESLA limit for the captured dark current is defined by its additional cryogenic loss. It should be kept below 50 nA per cavity [5].

In the beginning of 2006 the module test stand will become available. This installation will allow the test of accelerator modules independently of the TTF accelerator.

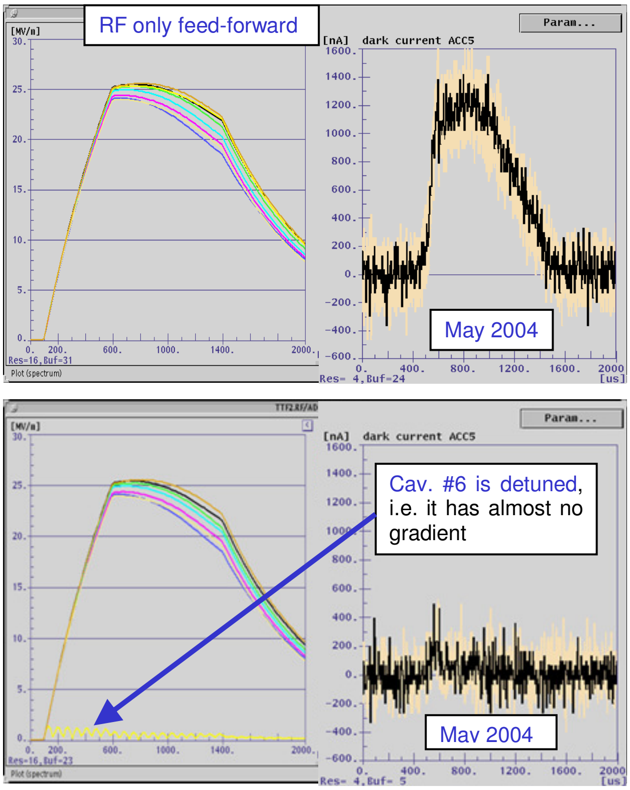

Figure 5: Dark current behavior of the cavities in the last accelerator module. Top: All cavities are tuned. Bottom: The cavity #6 has been detuned by a few kHz. The dark current is strongly reduced.

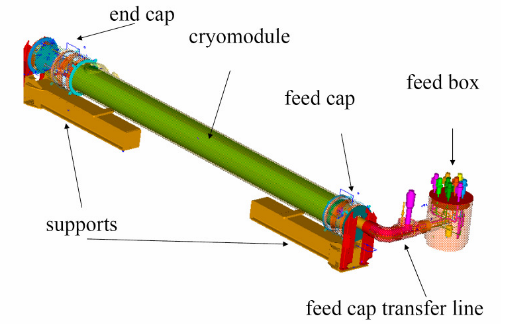

Figure 6: Layout of the module test stand. This will allow the test of accelerator modules independently of the TTF linac.

R&D ON CAVITIES

Electropolishing (EP) is the most promising surface preparation technique for superconducting cavities. The niobium material is removed in an acid mixture under the flow of an electric current. Sharp edges or tips are smoothed out and a very glossy surface can be obtained. It has been chosen to be the baseline cavity preparation for the XFEL as the time-consuming 1400°C furnace treatment for post-purification can be avoided.

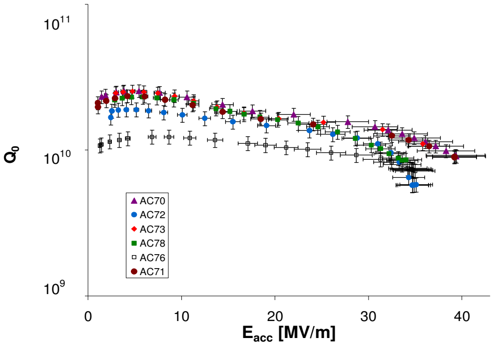

Figure 7: Several electropolished cavities yield gradients of more than 35 MV/m.

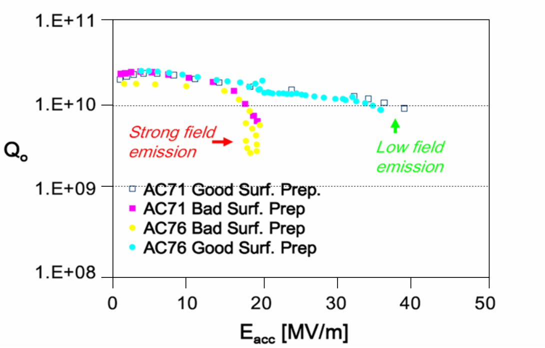

Figure 8: Examples for problems with field emission. Two cavities are shown which have been subjected to electropolishing twice. One of the tests shows strong field emission. The other tests show very good performance. So far the source of the contaminations has not been located.

The EP technique has been successfully transferred to nine-cell cavities within a joint KEK-DESY R&D program [6]. Since then DESY built a system for the electropolishing of nine-cell cavities. With this setup now a lot of operational experience has been accumulated. Several cavities have achieved accelerating gradients of more than 35 MV/m in vertical tests (see Fig. 7). One of these cavities could be tested inside an accelerator module and kept its excellent performance.

Recently, there have been problems with enhanced field emission (Fig. 8). The reason for this is not yet fully understood. There are hints of a contamination of the EP setup with sulphur [7].

Nonetheless, the experience gained with the setup will be used to start a study together with industry. So far, the costing of the cavity preparation for TESLA was based on etching and the 1400°C post-purification. Although the EP process is more complicated than etching, some cost reduction is expected due to the avoidance of the furnace treatment.

Single-cell R&D at TTF is focusing on the following items[8]:

- Qualification of new Nb suppliers
- Industrialisation of EP
- Rework the specification for fabrication of 9-cell cavity
    - Check the eight hours rule etc.
- Rework the Nb specification:
    - Nb with high thermal conductivity (RRR 700-900)
    - Check the Ta content
- Very large grain Nb material

As a first step now the DESY electron-beam welding machine has been qualified. A cavity built at DESY and electropolished at Henkel [9] has been successfully tested (figure 9). A gradient of more than 35 MV/m could be reached after 'in-situ' bakeout. The quench was located with a temperature mapping system. It is not located in the equator region.

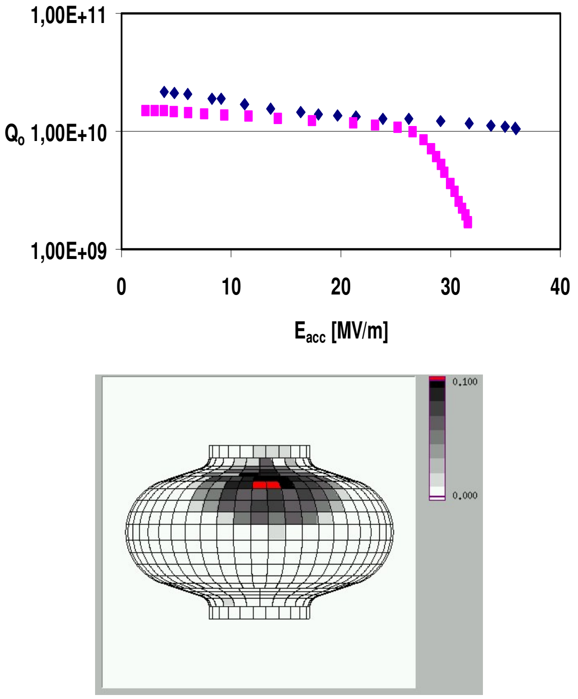

Figure 8: Test results of the first cavity welded at DESY. Top: A gradient of 35 MV/m could be reached after 'in-situ' bakeout (Blue curve). Bottom: The temperature map shows the quench location to be located far away from the equator.

ACKNOWLEDGEMENT

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