ACTIVITIES WITH SUPERCONDUCTING CAVITIES AT DESY

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Abstract

The activities with superconducting cavities at DESY aim to develop the technology needed to build a large-scale linear accelerator for the TESLA project. Within the framework of an international collaboration the TESLA Test Facility TTF [1] has been established at DESY. Since 1994 the infrastructure for handling and testing high gradient cavities is in operation. More than 50 9-cell cavities were fabricated by four different companies. Accelerating gradients as high as 30 MV/m were measured in vertical acceptance tests as well as in horizontal cryostats with completely equipped resonators. Three modules, each containing 8 resonators were installed and operated in the TESLA test facility linac. In 1998 the extension of the linac to a 1 GeV SASE FEL user facility was approved and is scheduled to be operational in 2002. Details of Nb material investigation, cavity treatment and measured performance as well as the linac operation will be presented.

1 INTRODUCTION

Superconducting cavities are under operation in accelerators for electrons or positrons (beta=1 structures) or for ions (beta<1 structures). Several proposals suggest this technology also for acceleration of protons (beta<1). At present the largest installation of superconducting structures operates at CERN. It consists of 288 four-cell resonators at a resonance frequency of 352 MHz [2].

There are two major advantages of superconducting accelerating structures as compared to a normal conducting layout:

- Higher accelerating gradients can be established under continuous wave conditions or for long pulses.
- Larger iris openings are allowed because the shape optimisation is not driven by the need of a high characteristic impedance R/Q as in the normal conducting design. Therefore wake field effects are substantially reduced.

Niobium is the favourite material to build superconducting cavities. The intrinsic properties of this superconductor allow accelerating gradients up to 50 MV/m. Best single cell cavities reached E_{acc} = 43 MV/m whereas multicell structures with all auxiliary components lack behind in performance.

Before reaching the critical field of a superconductor, two major limiting phenomena are observed in superconducting cavities: thermal breakdown of the cavity or loading by field emission from cavity areas with high surface electric fields. The breakdown is the consequence of a thermal runaway, driven by the heat flux of normal conducting areas ("defects"). The preparation of an absolutely clean surface, the quality control of the bulk niobium and of welds against foreign inclusions as well as the increase of the thermal conductivity of Nb are the major cures against breakdown. Field emission spots have been localised at mechanical protrusions but more dominant at small particles (10 - 50 µm size, "dust" particles) which both enhance the local electric field strength. Absolutely clean surfaces are the most important conditions to avoid field emission.

Within the framework of an international collaboration the TESLA Test Facility TTF [1] has been established at DESY. The aim is to explore the technology of high gradient superconducting cavities and to demonstrate the feasibility of a superconducting linac for a linear collider TESLA (TeV Energy Superconducting Linear Accelerator) [3]. The infrastructure for investigation and production of high gradient cavities has been established [4]. A 1 GeV test linac will demonstrate the performance of the superconducting accelerating system under realistic beam conditions. In addition to the linear collider application this test linac will be used to set up a FEL source which is based on the amplification of the radiation by the SASE principle (self amplified spontaneous emission).

2. CAVITY FABRICATION

The 1.3 GHz TESLA cavity consists of 9 cells with one higher order mode coupler on either beam pipe and one input coupler at one end [3]. It is fabricated from 2.8 mm sheets by deep drawing cups and welding by electron beam. The Nb sheet material is of high conductivity (RRR > 300, thermal conductivity at 4.2K is 70 W/(mK)). All sheets of the second production are checked for foreign inclusions or other material defects by eddy current [5]. The rejection rate by this quality control measurement is about 7 %. Four European companies were involved in the cavity production: ACCEL, CERCA, Dornier and ZANON. Since 1994 in total 54 nine cell cavities were manufactured and measured. The average gradient of the first 19 cavities (made from not scanned sheets) is

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22.7 MV/m. The next 25 cavities (from scanned Nb sheets) reached an average of <Eacc> of 25.3 MV/m. In both cases cavities with material or fabrication defects were excluded in the statistics. The latest cavities are

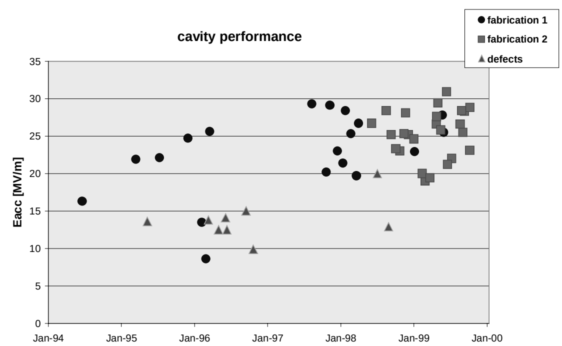

Fig. 1 Measured performance of all TESLA 9-cell cavities at the vertical acceptance test

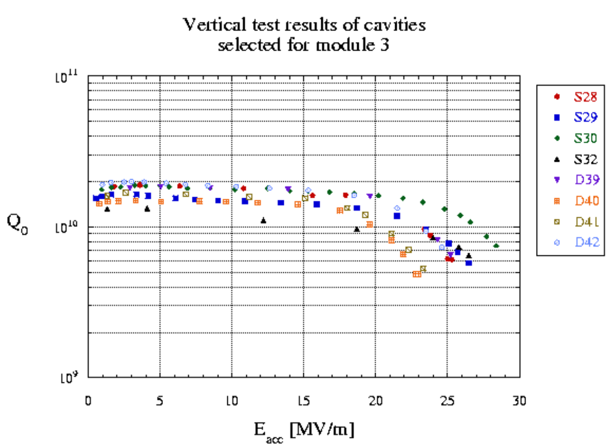

Fig. 2 Vertical test performance of the 8 TESLA cavities being selected for accelerator module 3

mainly limited in gradient by field emission. Some cavities show thermal instabilities by reasons not clearly understood: two point multipacting at the equator [6] around Eacc of 20 MV/m might be one reason.
Three modules, each containing 8 cavities [3] have been equipped and were operated in the TTF linac. Another batch of 8 cavities is selected for completing the fourth module. Presently 30 more cavities are ordered for the next modules.

3. LINAC OPERATION

The three first accelerating modules were equipped with cavities of gradient performance of 15 MV/m, 20 MV/m and 25 MV/m, respectively. They were installed and operated in the TTF-linac facility. Four beam experiments have been performed so far:

Run I (middle of 97)
Aim: commissioning of the thermionic gun, capture cavity and module I.
Major results:

- Fast beam on procedure,
- Eacc of 15 MV/m (12 MV/m) for short pulse (TTF pulses of 800 µsec) could be measured with beam in module I.
- No microphonics was detected,
- But: two cold tuners blocked; leak after warm up (beam-to-iso-vacuum).

After warm up the blocked tuners were investigated: parts with too tight mechanical tolerances were exchanged and TiN coating was implemented for better lubrification.

Run II (January - May 98)
Aim: test of modified tuner, commissioning of many beam line components.
Major results:

- All cold tuners operate,
- Calibration of beam monitor, current detector,…
- Strong deflecting higher order modes ("trapped modes") detected in two cavities by beam excitation.

Run III (December 98 - March 99)
Aim: operation of module I and module II, commissioning of the RF gun [7] and bunch compressor, test of components for the next SASE-FEL run, operate two modules with one klystron.
Major results:

- Eacc = 18.2 MV/m in module II (operated by one klystron),
- Typical operation at 12 MV/m with both modules driven by one klystron (limited by module I, but sufficient for all beam tests).

After warm up the leak in module I was localised at the cavity to beam pipe flange. The flange design has been modified meanwhile to a version with hard NbTi instead of pure soft Nb material at the sealing area.

Run IV (started in August 99)
Aim: commissioning of undulator I, operate module III at gradient of 25 MV/m, first try to operate the SASE-FEL [8].

At the time of writing this paper, cavities and couplers are being conditioned. Beam optics have been explored, especially at the undulator, to prepare a precise beam positioning for the SASE-FEL demonstration.

After run II several RF measurements have been done at cold and warm cavities to uncover the reason of the strong deflecting modes. Those modes belong to the third TE pass band (2.585 GHz) and are only weakly damped (at least one of the two polarisations). It seems that the cavity and the beam pipe form a resonator (the cut off frequency of the beam pipe for this field configuration is below 2.5 GHz) with a minimum of the standing wave pattern at the location of the HOM coupler. More investigation is needed to clarify the situation and to cure the problem.

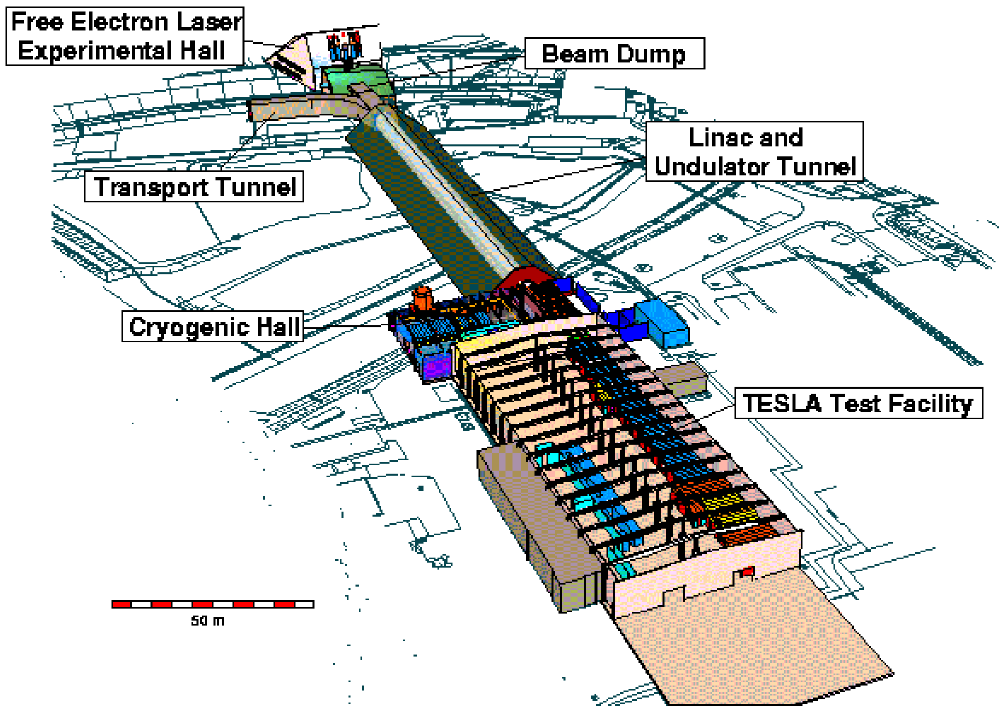

Fig. 3 Layout of the1 GeV TTF-FEL user facility: TTF hall with 500 MeV linac (front), 1 GeV extension tunnel (above ground, same design as the underground TESLA tunnel) and experimental hall downstream the linac. This hall will be used as FEL exhibition building during EXPO 2000 during summer 2000. Commissioning for the FEL facility is scheduled for 2002.

4. TTF-FEL EXTENSION

The requirements of a 4 generation light source are described by

- Full transverse coherence,
- Sub-picosecond pulse length,
- High average flux and brilliance,
- Fast tunability of wavelength.

The scientific application is expected in the field of microscopy, holography, dynamics of chemical reaction, cluster target etc. One promising technology for such a light source is a linac driven free electron laser. The high beam quality of a superconducting linac promises to operate a high gain SASE-FEL type of light source. Therefore the necessary hardware (bunch compressor, 6 m undulator, beam diagnostics) were installed in the TESLA Test Facility Phase 1. Presently (run IV) the linac driven laser is being commissioned. It is the aim to prove the SASE principle for a single pass FEL at 42 nm. In 1998 the Test Facility Phase 2 was approved: a 1 GeV SASE-FEL at a wavelength of 6 nm [8]. The superconducting linac is basically a factor of two extension of the original TTF linac with an experimental hall at the down stream end. This user facility is expected to be commissioned in 2002.

5. SUPERSTRUCTURE

The idea of the superstructure [9] is to couple non-resonant a chain of multicell cavities ("sub-units") to a string, which is fed by only one input coupler. The basic advantages are

- To decrease the number of input couplers for the linac,
- To increase the filling factor because the distance between sub-units can be made very short.

After theoretical calculations and measurements on Cu-cavities one superconducting superstructure is under production. It consists of four sub-units (four 7-cell cavities). After vertical test of the 7-cell resonator the

string of 4 subunits is realized by flange connections. A beam test in the TTF linac is scheduled for early 2001.
The aim of this test is to demonstrate the calculated energy spread and to test the higher order mode behaviour of the structure.

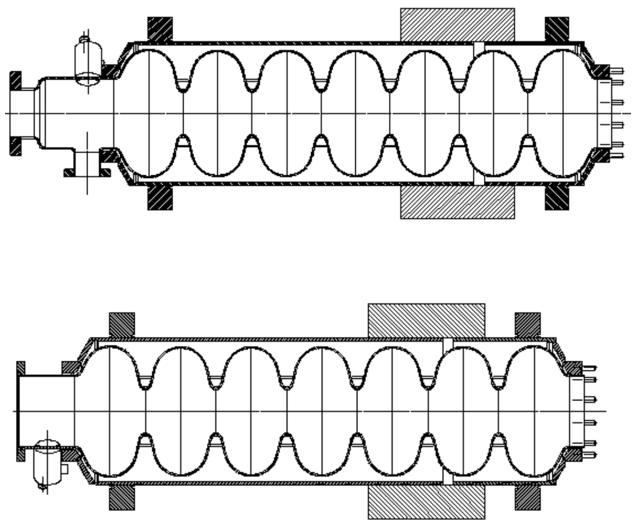

Fig. 4 Layout of the superstructure sub-units for the 2001 beam test. One subunit with input coupler port (see upper figure) is flanged to three standard sub-units to form a 28-cell superstructure

6. R&D ACTIVITIES

6.1 Electropolishing of Nb resonators

The maximum accelerating gradient of superconducting cavities might be limited by thermal instabilities (also called quench), field emission current or decrease of the quality factor without any indication of field emission. The first limitation can be caused by defects in the material or welds. Field emission is caused by tunneling electrons through the metal surface at the location of enhanced electric surface fields like protrusions or "dust" particles. The third limitation is not clearly understood but might be due to some global heating of the inner surface. The standard chemical cleaning of niobium results in a relatively rough surface. Electropolished surface can have a mirror-like finish. Encouraging results of electropolished single cell cavities have been recently published at KEK [10]. Therefore a joined effort between CERN, Saclay, KEK and DESY has been started to investigate electropolishing methods for single and multicell cavities. A remarkable result of Eacc = 34 MV/m could be measured in a single cell cavity after electropolishing but without any heating or Ti treatment at 1400 C [11]

6.2 Seamless cavities

The production of seamless cavities promises to be cheaper and faster than the standard method of EB-welding cups. Therefore hydroforming (at DESY) and spinning (INFN Legnaro-DESY collaboration) are investigated since some time. The unsolved challenge with the hydroforming process is the supply of high quality Nb tubes with isotropic mechanical properties. Progress has been gained in this field by extensive material research. The first full-scale single cell resonator could be manufactured without intermediate annealing. More details are given by [12].
Several single and multicell Nb resonators were fabricated by spinning. These resonators are limited by a drastic increase of RF loss around 15 MV/m gradient. The reason for this behaviour is not clearly understood by seems to be caused by the very rough inner surface. One resonator reached a gradient of 25 MV/m after a combination of grinding, heating and heavy chemical polishing. Details and latest results are presented in [11] and [13].

6.3 Multipacting calculations

Multipacting in RF-structures has been intensively investigated in collaboration with the Rolf Nevanlinna Institute, Helsinki [14]. A complete package for calculation of multipacting resonances in 2D geometries including ceramics has been established and is under test at DESY. This program package includes electromagnetic field calulations, trajecting calculations, graphical display routines and handling of input/output procedures. After thorough testing it will be made available to interested users. For latest information please contact katrin.lando@desy.de.

6.4 Nb sheet quality control

All sheets of the second cavity production (since 1998) have been scanned with eddy current for material defects and foreign inclusions [5]. With the first apparatus the sheets were scanned by a moving coil. The acceleration of the coil system at the beginning and at the end of the linear scan produced vibrations of the scanning table. This noise limited the sensitivity of the eddy current response because the signal also depends on the distance of the coil to the Nb surface. In an improved layout the Nb sheet rotates while the coil moves slowly like the tangential arm of a record player. Hereby the sensitivity could be increased and this arrangement is more flexible for different sizes of sheets to be tested [5].
As alternative method high T_c-SQUIDS were used as very sensitive magnetometric sensors. Nb sheets should show no magnetisation unless there are magnetic inclusions. Astonishingly, the magnetic field of thermocurrents in the Nb sheet can be detected. The Nb sheet is rotated and the spot of the Nb plate underneath the SQUID sensor is heated by hot air jet. Nb sheets of different manufacturers

show quite different thermo current distribution. Further investigations are on the way to correlate these findings with the superconducting properties of Nb [5].

7. INPUT COUPLERS

Different types of coaxial input couplers have been built for the TTF linac [15]. One general observation is that conditioning of input couplers is very time consuming. The mechanism of conditioning is the desorption of gas layers from the RF surface. Obviously desorption by impact of low energy electrons plays a dominant role. These electrons might be produced by multipacting. The increase of the pumping speed and/or the elimination of multipacting will increase the speed of conditioning. The coating of a thin film of NEG (non-evaporating getter) material on the RF surface could help in two respects:

- There is in situ pumping,
- The secondary yield of the NEG film is near to 1.

These films (TiZrV) have been developed at CERN [16] and only need an activation temperature of 250 C. Therefore the idea is to coat the inner coaxial parts of the coupler with a thin NEG film and activate the pumping by bake out of the assembled coupler. In a joined effort between CERN and DESY NEG coatings are examined in respect to the multipacting behaviour and the RF performance. First results indicate, that multipacting is nearly completely suppressed after the activation bake out at 250 C. A short opening of the test resonator to dry nitrogen for about 30 min did not deteriorate the quality of the NEG film. In the near future the coating of a TTF input coupler is foreseen.

8. DATA BANK

A database has been established to testify relevant cavity data: Nb properties, mechanical cavity data, parameters of treatment (heating, chemistry, firing, high pressure water rinsing, assembly), results of superconducting measurements, status of infrastructure, etc [17]. This data bank will be made available on the DESY Web site. For access procedure please contact dieter.gall@desy.de.

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REFERENCES

[1] D. Edwards (Editor) "TESLA TEST FACILITY - DESIGN REPORT", TESLA-Report 95-01 (1995)

[2] G. Cavallari et al, Proc of the 4th EPAC (London), vol 3 (World Scientific) p 2042 - 2044 (1994)

[3] R. Brinkmann, G. Materlik, J. Rossbach, A. Wagner (Editors), "CONCEPTUAL DESIGN OF A 500 GeV e+e- LINEAR COLLIDER WITH INTEGRATED X-RAY LASER FACILITY", DESY 1997-048/ECFA 1997-182 (1997)

[4] D. Proch, "STATUS OF THE TESLA TEST FACILITY", Particle Accelerators, vol 60, p 53-72 (1998)

[5] W. Singer et al, "QUALITY CONTROL AND PURIFICATION HEAT TREATMENT OF NIOBIUM FOR TTF", this workshop

[6] W. Weingarten, Proc. of the 2nd Workshop on RF Superconductivity, Ed. H. Lengeler, CERN, Geneva, Switzerland, p 551 (1984)

[7] S. Schreiber, "FIRST RUNNING EXPERIENCE WITH THE RF GUN BASED INJECTOR OF THE TESLA TEST FACILITY LINAC', 21st FEL Conference, Hamburg (1999)

[8] "A VUV FREE ELECTRON LASER AT THE TESLA TEST FACILITY AT DESY - CONCEPTURAL DESIGN REPORT", DESY Print, June 1995, TESLA-FEL 95-03 (1995)

[9] J. Sekutowicz et al., "Nb PROTOTYPE OF THE SUPERSTRUCTURE FOR THE TESLA LINEAR COLLIDER", this workshop

[10] K. Saito et al, "HIGH GRADIENT PERFORMANCE BY ELECTROPOLISHING WITH 1300 MHz S MULTI-CELL NIOBIUM SUPERCONDUCTING CAVITIES", this workshop

[11] L. Lilje, "PERFORMANCE LIMITATION IN SC CAVITIES AT TTF-CURRENT STATUS AND FUTURE PERSPECTIVES', this workshop

[12] H. Kaiser et al, 'HYDROFORMING OF BACK EXTRUDED NIOBIUM TUBES', this workshop

[13] V. Palmieri, "SPINNING OF TESLA-TYPE CAVITIES', this workshop

[14] D. Proch, J. Sarvas, E. Somersalo, P.Yla-Oijala, 'COMPUTATIONAL METHODS FOR ANALYZING ELECTRON MULTIPACTING IN RF STRUCTURES', Particle Accelerators, vol 59, p 107-141 (1998)

[15] W.-D. Moeller, 'HIGH POWER COUPLER FOR TESLA TEST FACILITY", this workshop

[16] C. Benvenuti et al, 'DECREASING SURFACE OUTGASSING BY THIN FIM GETTER COATINGS', Vacuum, vol 50, p 57-63 (1998)

[17] D. Gall et al, THE SUPERCONDUCTING CAVITY DATABASE FOR THE TESLA TEST FACILITY', this workshop