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The Vacuum System for the Superconducting Linac of the TESLA Test Facility

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Abstract

Among the different approaches towards a next generation 500 GeV e^+e^- linear collider the TESLA design uses superconducting accelerating structures operating at 1.3 GHz with a gradient of 25 MV/m. Presently the TESLA Test Facility, which includes a prototype linear accelerator with superconducting cavities, is build up at DESY/Hamburg to serve as an R&D tool. First electrons have been accelerated in spring 1997. In the present state of the project two cryomodules, each containing 8 solid niobium cavities are installed. One of the major objectives for the beam vacuum system is to preserve the cleanliness of the superconducting cavities surfaces and thus the operation at high gradients and high Q. Contamination by any sort of dust or condensation of gases during assembly and operation has to be absolutely avoided. Thus all vacuum components are carefully cleaned in clean rooms to make them particle free. Local clean rooms are used for installation of the components into the linac. A description of the linac vacuum system, the running experience and the present status of the project will be given.

Key words: accelerator vacuum, superconducting cavities, TESLA, dust contamination

1 Introduction

A high energy e^+e^- linear collider with a center of mass energy of 500 GeV and a luminosity exceeding 10^{33}/cm^2/s is considered as the next generation of high energy accelerators following the LHC at CERN. This machine will serve as an essential tool to search for fundamental constituents of matter and their interactions and to address the problem of mass generation in the Standard Model. Several groups worldwide are pursuing different linear collider design efforts. The fundamental difference of the TESLA (TEV-Superconducting Linear Accelerator) approach compared to other designs is the choice of superconducting accelerating structures [1].

For the TESLA 9-cell cavities operated at 1.3 GHz an accelerating field of 25 MV/m at a quality factor of $Q_0 > 5 \cdot 10^9$ was envisaged to reach the desired energy within a reasonable length of about 30 km of the accelerator. The challenge of pushing the superconducting linac technology to a high accelerating gradient and at the same time reducing the cost per unit length, both necessary in order to be competitive with conventional approaches, is considerable, but the advantages connected with this technology are ideal for an optimum performance in terms of the achievable luminosity. In addition, this technology offers the best choice to use the linac as driver of a X-ray Free Electron Laser (FEL) working in the Self Amplified Spontaneous Emission (SASE) regime thus offering the implementation of a coherent synchrotron radiation source into the TESLA project.

At present, more than 30 institutes from Armenia, China, Finland, France, Germany, Italy, Poland, Russia and the USA participate in the TESLA Collaboration and contribute to the TESLA Test Facility (TTF) [2] presently under construction at DESY (Hamburg). TTF com-

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prises the complete infrastructure for the treatment, assembly and test of superconducting cavities as well as a prototype superconducting linac for testing machine critical components and a proof of principle experiment for the SASE FEL. For the TTF linac superconducting cavities with gradients of at least 15 MV/m are required.

The construction of the superconducting TTF linear accelerator is divided into two stages. Phase I is close to completion. Figure 1 shows the present layout of the 120 m long linac including two cryo modules, each containing 8 superconducting cavities, and a 14 m long undulator. In Phase II the energy will be increased to 1 GeV by extending the linac to about 200 m and installing up to 64 superconducting cavities as well as a SASE FEL of 30 m length.

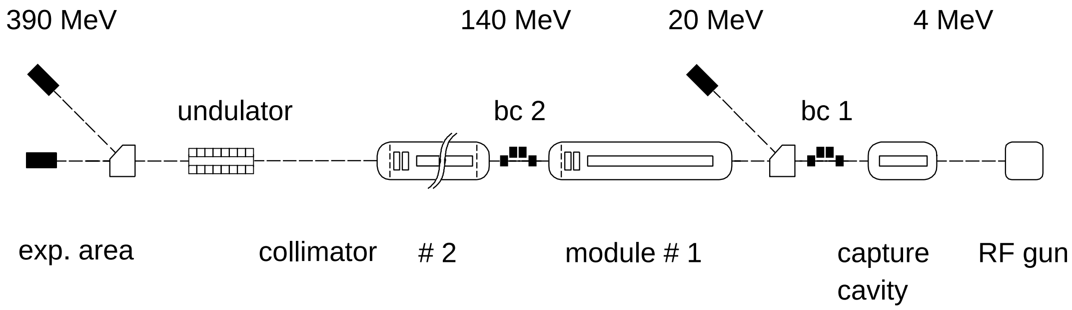

Fig. 1. Present layout of the superconducting linac of the TESLA test facility. The electrons are produced by a RF gun and accelerated by the capture cavity and two modules, each containing 8 superconducting cavities.

2 Superconducting Cavities for TTF

The 1.3 GHz TTF cavities are 9-cell structures fabricated from RRR 300 pure Niobium sheets by deep drawing and electron beam welding. In order to cool the 1.3 m long cavity to 2 K the 9-cell structure is surrounded by a titanium tank filled with superfluid Helium as indicated in Figure 2. The main power coupler as well as the two higher order mode (HOM) couplers and a pick-up are mounted at the side flanges.

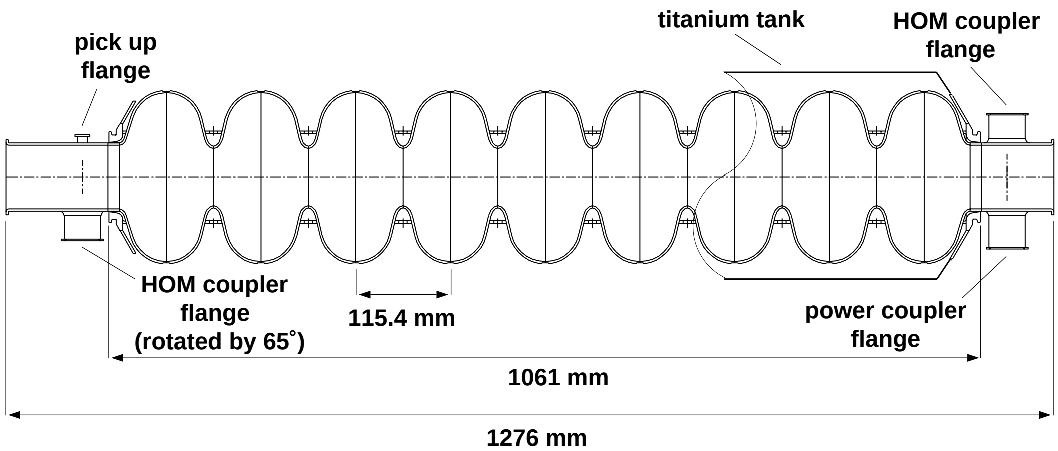

Fig. 2. Schematic drawing of the 1.3 m long TTF 9-cell cavity. The main power coupler as well as higher order mode (HOM) couplers and a pick-up are mounted at the side flanges.

In order to achieve the desired high gradients of 25 MV/m at $Q_0 > 5 \cdot 10^9$ the superconducting cavities must have ultraclean surfaces especially on the inside. Therefore they have to undergo special treatment and assembly procedures comparable to those used for the production of highly integrated semiconductors. Cleaning and assembly of the cavities is performed in a dust free environment starting with chemical etching of the cavity surface. As dust particles can act as field emitters and thus limit the performance, the cavities as well as all auxiliary components are cleaned to class 10 level using an ultrasonic bath, high pressure rinsing, etc. followed by the complete assembly of the cavities with all auxiliary components in a clean room of class 10.

Additionally a heat treatment of the niobium cavities is necessary. At present the cavities are heated up to 800˚C for 2 hours in an ultra high vacuum furnace while keeping the pressure below 10^{-5} mbar usually followed by a second heat treatment at 1400˚C in another UHV furnace to increase the RRR and homogenize the material. Here titanium is used to getter gases like hydrogen, oxygen and nitrogen. Due to this high temperature treatment the niobium gets softened.

3 The TTF Vacuum System

Vacuum Requirements

The requirements to the vacuum system of the TTF linac are mainly determined by the ambitious goal to reach high accelerating gradients in the superconducting cavities. As explained above dust particles can act as field emitters and thus limit the performance of the superconducting cavities. As the 2 K cold cavities are an integral part of the beam pipe they act as huge cryo pumps. Therefore the risk to contaminate the superconducting cavities with particles and to condensate gas from other vacuum components during assembly and operation needs to be absolutely avoided. The interaction between beam and residual gas is however uncritical and synchrotron radiation is negligible in case of the TTF linac.

Overview of the TTF Linac Vacuum System

The vacuum system of the TTF linac is split into cold and warm parts . The first accelerating structure (capture cavity, see Figure 1) and the two cryo modules are operated at 2 K and therefore surrounded by an isolation vacuum. The warm vacuum system contains a RF-gun as electron source, a bunch formation system including bunch compression (bc 1, bc 2), the undulator with a collimation section and the experimental area for beam diagnostic elements as well as FEL diagnostics.

Cold Vacuum System

One important item of the cold vacuum system was the development of a reliable flange connection between the superconducting niobium cavities and the stainless steel bellows pieces in between neighbouring cavities. The cavities are now equipped with rigid niobium-titanium flanges (Nb/Ti55) electron beam welded to the niobium end tubes. Massive aluminium rings are used as gaskets. This flange design [3], shown in Figure 3, fulfills all requirements of UHV leak tightness at room temperature and 2 K when immersed in liquid or superfluid helium as well as an easy handling during assembly. It is superior to the previous solution using niobium sealing lips of 3 mm thickness, split stainless steel rings and spring type gaskets (Helicoflex) by the following reasons. Due to the smaller specific weight the niobium-titanium flanges can be directly welded to the cavity end tubes. Compared to the previous niobium sealing lips the niobium-titanium flanges withstand the high temperature heat treatment without softening such that the assembly of the flange connections became reliable and the earlier frequent UHV-leak problems have been eliminated. In contrast to the spring type gasket particles can easily be removed from the aluminium rings inside the clean room.

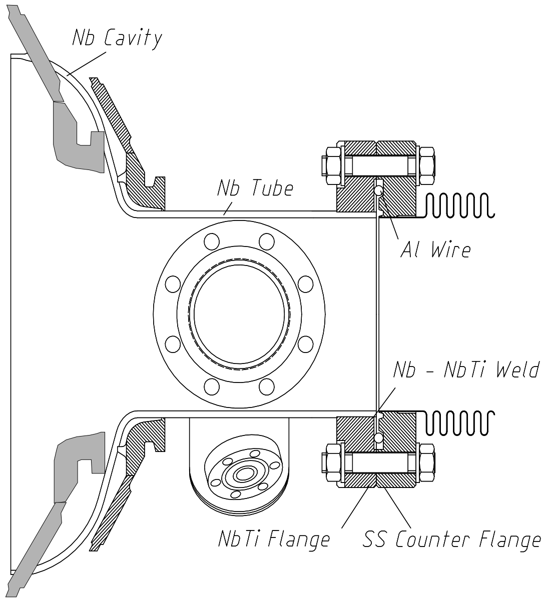

Fig. 3. New flange design of the TTF niobium cavities using niobium-titanium flanges and massive aluminum rings.

The main power RF input coupler has two ceramic windows, one at a temperature of 70 K during operation and one at room temperature. This design enables to close off the cavity completely by mounting the coupler up to the first window in the clean room, thus preventing any contamination during the further assembly of the module described below. Additionally, gas and dust are prevented to enter the cavities in case a crack in one of the ceramic windows would occur during operation.

Eight cavities and a superconducting quadrupole with integrated beam position monitor are grouped into 12 m long strings as shown in Figure 4. The cavities are connected via copper coated bellows without RF-shields. The complete string is assembled in a clean room class 10. Once evacuated the string is closed off by all metal manual valves at both ends and inserted into the module tank. The isolation vacuum is similar to the HERA design [4].

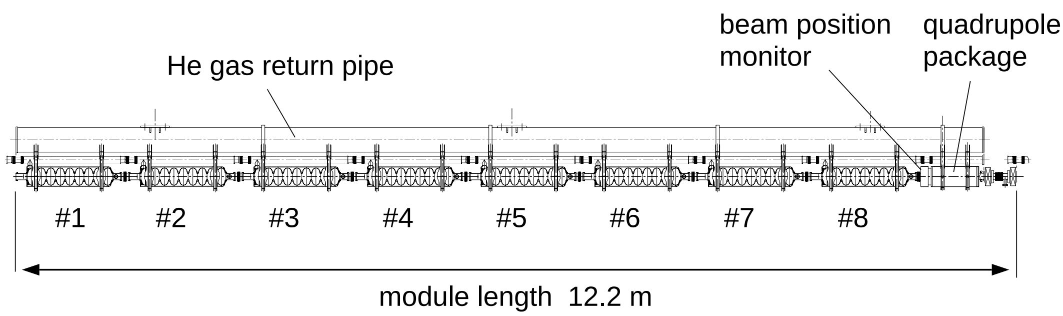

Fig. 4. Schematic drawing of the TTF/TESLA module containing eight superconducting cavities and a superconducting quadrupole with integrated beam position monitor.

Warm Vacuum System

The warm vacuum system is pumped by more than 30 titanium sublimation pumps with a pumping speed of 1000 l/s (H_2) in combination with small ion getter pumps (60 l/s), which are also used for pressure read out. Modified power supplies enable to read out pressures as low as $3\cdot10^{-11}$ mbar. No additional pressure gauges are installed in the beam line vacuum. The system is segmented by 12 all metal gate valves. In addition two fast shutters are installed downstream of the second module to protect the cold cavities in case of a vacuum break in the experimental area of the linac.

Most of the vacuum chambers of the warm system are made from stainless steel (316LN) and sealed by Cu-Conflat gaskets. In order to minimize the risk of particle and gas contamination of the superconducting cavities from other vacuum components the stainless steel chambers are vacuum fired at 950 ˚C to reduce the outgassing of H_2. Additional cleaning to make the vacuum components particle free as well as the assembly work is done in clean rooms using procedures similar to the treatment of the superconducting cavities. This turned out to be quite time consuming. Local clean rooms are used for the installation into the linac. Special care is given to the pump down and venting procedures like using oil free pump stations, small apertures for pump down and venting to avoid strong turbulences of the gas flow, particle filters to clean the dry nitrogen for venting etc. So far no in-situ bake out of the system has been performed.

The pressure is below 10^{-10} mbar in most parts of the linac as shown in the graph in Figure 5. The significantly higher pressure in some parts of the machine is well understood like in the undulator section (1UND3). Here the 4.5 m long aluminium vacuum chambers [6] with an inner diameter of 9.5 mm strongly limit the conductance in this area. Due to the compact design of the undulator pumping is only possible in between the three undulator sections. In the experimental area several components with low conductances and high outgassing rates are installed.

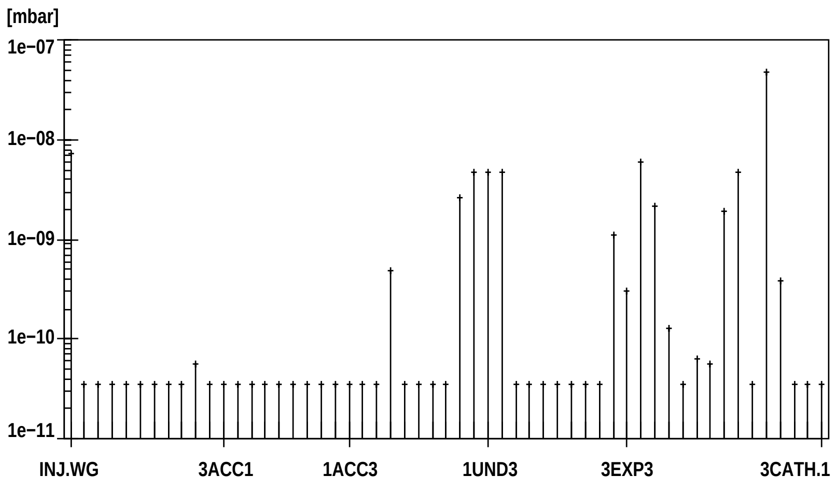

Fig. 5. Pressure versus position in the TTF linac as measured with the ion getter pumps. In the undulator section (1UND3) and the experimental area (3EXP3) the pressure is substantially higher due to low conductances and components with high outgassing rate.

Vacuum Control System

The vacuum control system is built in a way to guarantee a self safe operation of all components like pumps, valves and pump stations by using programmable logic controllers (PLC) and special μ-processors. All information is accessible by computer controlled readout either locally at the machine or via network from terminals. The components are fully remote controlled. Automatic error diagnostic tools and long ranging archive systems are available. These tools turned out to be quite helpful not only to the vacuum experts but also to the operators of the machine in order to correlate the behavior of other components of the linac with vacuum related issues.

The vacuum control system of the TTF linac is an integral part of the general DOOCS control system of the machine [5]. In order to build up this compact control system standard as well as in house developed readout and control electronic is used.

4 Conclusions

In order to prepare the TESLA 500 GeV e^+e^- collider the TESLA Test Facility has been set up. It serves as an R&D tool to develop superconducting cavities with accelerating gradients of 25 MV/m as well as to test machine critical components in a prototype superconducting linear accelerator.

The superconducting TTF linac started beam operation in spring 97. At that time electrons from a thermionic gun were accelerated in a simplified set up using only one module with 16.5 MV/m resulting in a total energy of 125 MeV. At present a RF gun, two modules reaching almost the goal of 20 and 25 MV/m, two bunch compressors and a 14.5 m long undulator with collimation system are installed. The next step is to demonstrate the proof of principle of the SASE FEL. In its final stage the TTF linac should reach an energy of 1 GeV and turn into a SASE FEL user facility after 2002.

For the successful operation of the superconducting cavities a high level of cleanliness of all vacuum components, especially with respect to particles is required. Special cleaning and installation procedures under clean room conditions have been established to minimize the risk of particle and gas contamination of the superconducting cavities from other parts of the vacuum system. The vacuum system is running without major problems so far. A reliable sealing technique using niobium-titanium flanges and massive aluminium gaskets has been developed for the superconducting niobium cavities. No degradation of the cavity performance in the TTF linac compared to previous tests of the 9-cell structures in a vertical or horizontal cryostat has been observed so far.

The superconducting cavities presently installed in the TTF linac already exceed significantly the original envisaged accelerating gradients of E_{acc} = 15 MV/m for the prototype linac. Figure 6 shows the quality factor Q_0 versus maximum accelerating gradient E_{acc} for all 9-cell cavities as tested so far in a vertical cryostat [7]. There is a substantial improvement in performance between the cavities from the first and second production series. The majority of cavities clearly perform better than the original TTF goal, the number of cavities exceeding the TESLA goal is steadily increasing.

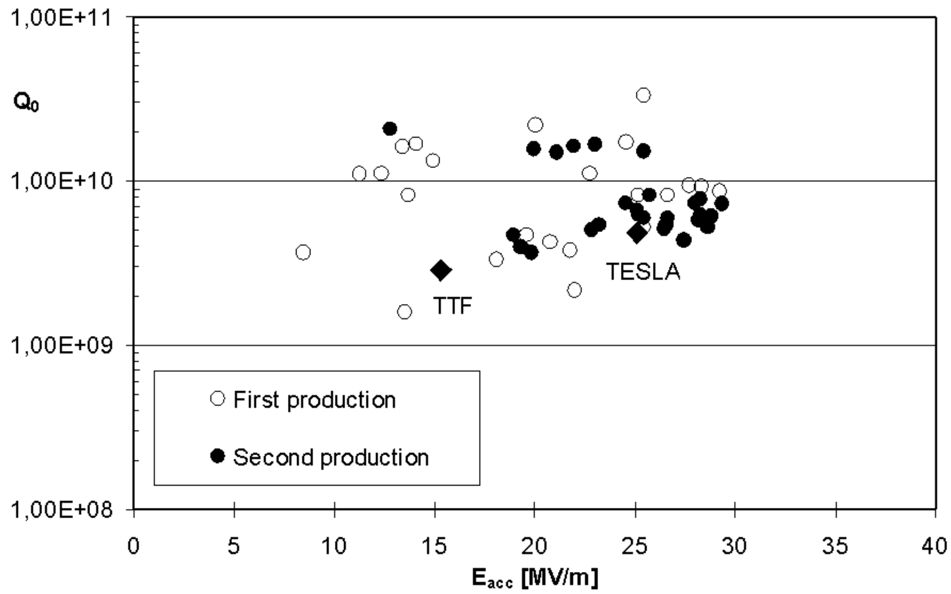

Fig. 6. Quality factor versus maximum accelerating gradient of the superconducting TTF 9-cell cavities as measured in a vertical cryostat. Also indicated are the envisaged values for the TTF and TESLA 500 linac.

Acknowledgement

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