A New Flange Design for the Superconducting Cavities for TESLA

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Abstract

In order to achieve accelerating gradients of 15-25 MV/m with the superconducting cavities in the TESLA Test Facility, considerable effort is put into preparing the cavities and the auxiliary components to avoid field emission due to particle contamination. The particle cleanliness has to be preserved throughout the whole assembly procedure of the cavities. Most crucial is the mounting of the flange connections which have to be UHV-leaktight with the cavities immersed in superfluid helium. In the present design, the niobium cavities are fabricated with Nb sealing surfaces with a thickness of 3 mm. Split stainless steel rings and spring-type gaskets (Helicoflex) are used to provide UHV-tight connections to the stainless steel counter flanges. This design has several disadvantages. The gaskets can not be properly made “particle-free” and the handling of the split flanges may contaminate the cavities during assembly. Moreover, the sealing surfaces of the Nb cavities get quite soft during the 1400˚C heat treatment, which often results in leak problems due to plastic deformations. An alternative approach are NbTi-flanges directly welded to the Nb cavities. They should allow an easier assembly of the counter flanges. Various types of spring-less gaskets are under investigation and the results will be presented.

1 Introduction

The TESLA Test Facility (TTF) is a 500 MeV superconducting test linear accelerator being built at DESY/Hamburg [1] as an R&D tool for the proposed 500 GeV e^+e^- TESLA linear collider [2]. The particles are accelerated by niobium cavities operating at a frequency of 1.3 GHz. In order to reach the desired beam energy within a reasonable length, cavities with an accelerating gradient of > 25 MV/m at an unloaded quality of $Q_0 > 5 \cdot 10^9$ need to be developed.

The superconducting cavities are made from pure niobium sheet material of RRR > 300 and cooled by saturated superfluid helium in a bath cryostat. At present the 1.2 m long nine cell cavities are fabricated by deep drawing of cups followed by electron beam welding. The beam tubes (diameter 78 mm) as well as the tubes for the main power coupler, the pick up and two higher order mode couplers are electron beam welded as well. Fig. 1 shows a schematic drawing of a cavity.

In order to achieve the desired high gradients the superconducting cavities must have ultraclean surfaces especially on the inside and therefore 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

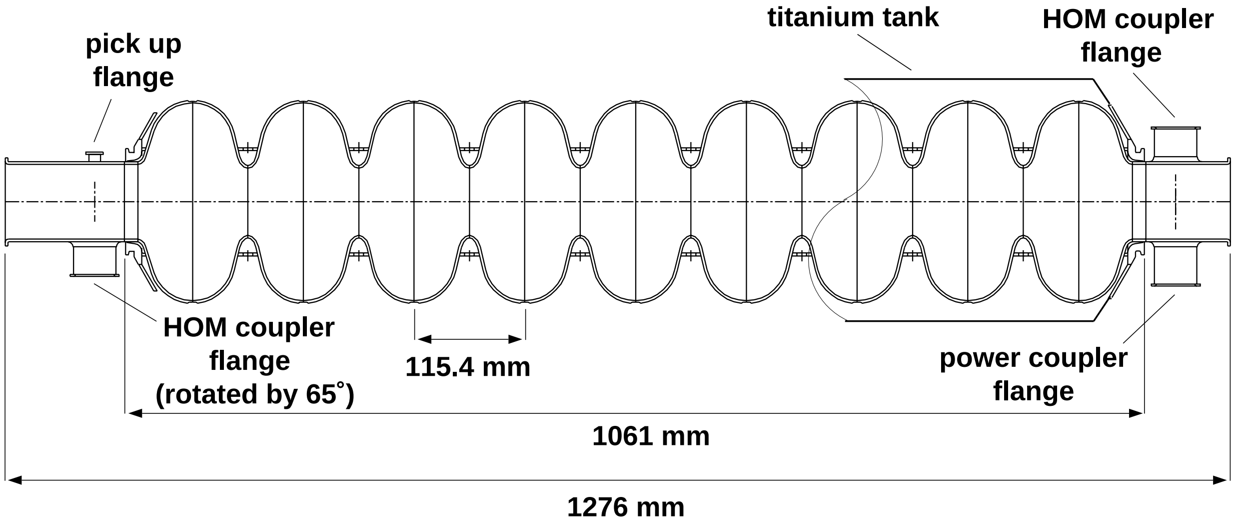

Figure 1: Schematic drawing of the TESLA/TTF cavities.

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. The assembly of the cavities with all auxiliary components is done in a clean room of class 10.

Additionally a heat treatment of the niobium cavities in an ultra high vacuum furnace is necessary. At present the cavities are heated up to 800˚C for 2 hours while keeping the pressure below 10^{-5} mbar. This heat treatment is usually followed by a second one with a bakeout cycle of 1 h at 1400˚C and 3 h at 1350˚C to increase the RRR and to homogenize the material. Here titanium is used to getter gases like hydrogen, oxygen and nitrogen.

The cavity performance is tested in a vertical cyrostat filled with superfluid helium. Cavities fulfilling the specifications are welded into a titanium tank as shown in fig. 1 that serves as a liquid helium container.

2 Connecting the Cavities to other Components

The flange connections have to fulfill several requirements: During assembly of the flange connections the previously cleaned cavities must be kept free of particle contamination. The connections have to be UHV-tight at room temperature with a leak rate $<10^{-10}$ mbar l/s as well as UHV-tight at 1.8 K with the cavity immersed in superfluid He for the performance test in a vertical cryostat. In addition the flanges on the cavity have to withstand the high temperature treatment at 1400˚C without degradation of the mechanical stability of the UHV-sealing surface.

3 Present Flange Design

In the present design shown in fig. 2, the niobium cavities are equipped with niobium sealing surfaces of 3 mm thickness which are bent over from the tubes. Split stainless steel rings are mounted on the cavity side while the counter flanges are made from stainless steel. Spring type gaskets (Helicoflex) are used. In order to reduce particle production during assembly special stainless steel or CuNiSiL screws and CuNiSiL nuts are used.

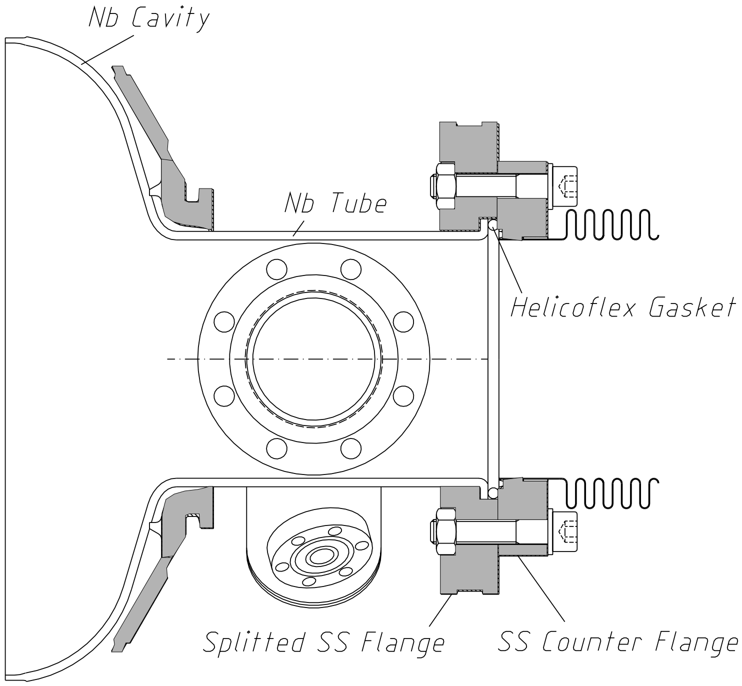

Figure 2: Present flange design of the niobium cavities for TESLA/TTF.

The present design has the following disadvantages: The Helicoflex seal can not be cleaned to class 10 level due to the spring inside the aluminum jacket. Thus it is an obvious source for particle contamination during assembly. The mounting of split flanges turned out to be complicated in handling and may lead to enhanced particle production as explained in more detail in [3]. Another severe disadvantage is that the niobium sealing surfaces of the cavities become soft during the 1400˚C heat treatment (tensile strength 5 MPa) which frequently leads to UHV-leak problems due to plastic deformation of the sealing surfaces.

4 New Flange Design

Alternative flange designs have been investigated with the aim to simplify the assembly, to achieve higher reliability with respect to UHV-tightness and to use a gasket with better cleanroom compatibility. The proposed solution is to use rigid flanges on the cavity and massive gaskets without a spring.

The most promising flange material has been found to be a Niobium-Titanium alloy of 45 weight percent Nb and 55 weight percent Ti (Nb/Ti55). This alloy can be directly welded to niobium by electron beam welding. It also withstands a heat treatment of 1400˚C without loosing its mechanical strength. Both the tensile strength σ_{02} and the hardness are comparable to those of stainless steel and substantially better than for pure niobium, see table 1.

The etching rate of NbTi in the standard chemical solution (HF/HNO3/H3PO4 [1:1:2]) used for the cavity treatment has been measured for a slightly different alloy (Nb/Ti48) than used for the flange material. The results however should not differ substantially. The etching rate of non heat treated Nb/Ti48 is a factor of 1.4 higher than for pure Nb, and a factor of 1.6 after the 1400˚C heat treatment. This implies that the NbTi flanges and the sealing surfaces need to be protected by a cover during the chemical etching of the cavities.

Table 1: Measured tensile strength σ_{02} and hardness of NbTi (45% Nb and 55% Ti), pure niobium and stainless steel (1.4429) before and after heat treatment at 800˚C resp. 1400˚C.

material	specific weight [g/cm^3]	tensile strength σ_{02} [MPa]	hardness
Nb/Ti55	6.3	370	165 HV10
Nb/Ti55 annealed (800˚C)			165 HV10
Nb/Ti55 annealed (1400˚C)		500	160 HV10
Nb	8.6	48	60 HV0.05
Nb annealed (1400˚C)		5	60 HV0.05
stainless steel (1.4429)	8.0	300	180 HV10

In the new flange design as shown in fig. 3 the Helicoflex gaskets are replaced by massive aluminum rings, which can easily be cleaned to class 10 level. The rings have a thickness of 5 mm for the beam tube and the main power coupler flanges and 2 mm for the small pick up flanges.

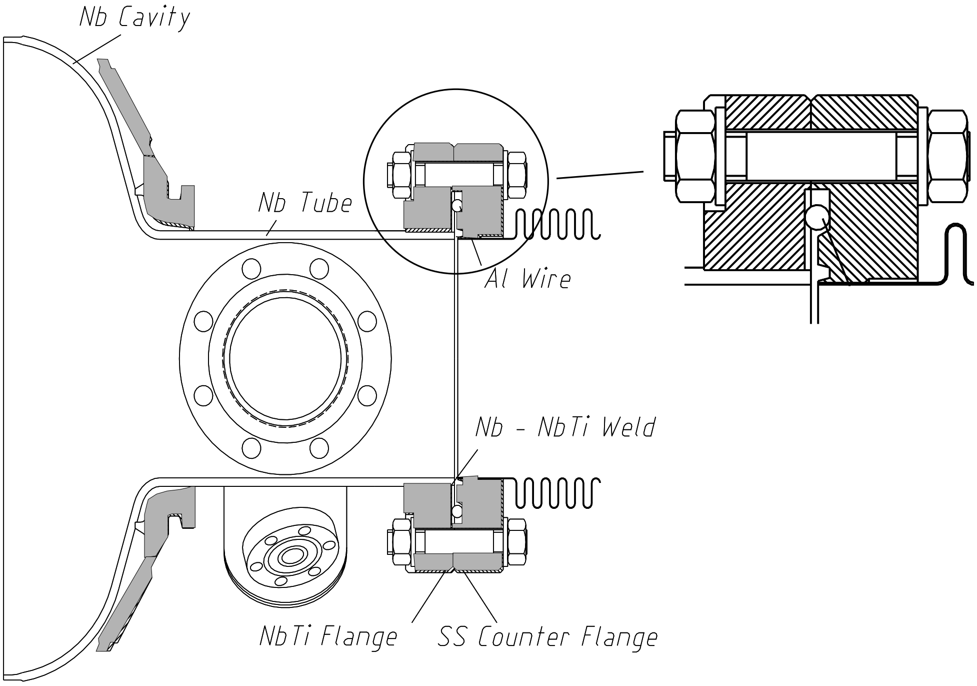

Figure 3: New flange design of the niobium cavities for TESLA/TTF with enlarged view of the sealing area.

To verify the UHV-tightness at temperatures below 4 K with the flange connection immersed in liquid or superfluid He an extensive test program has been performed using a cryostat as shown schematically in fig. 4. The test flange is connected to a stainless steel counter flange. The system is evacuated by a turbomolecular pump. The pressure is measured using a Penning gauge. A leak of the vacuum system located inside the cryostat is immediately indicated by a He leak detector, once liquid He is filled into the cryostat. The temperature of the NbTi flange is measured using a PT100 low temperature resistor. Filling liquid He into the cryostat temperatures of 4 K are reached. By additional pumping of the volume above the liquid to 17 mbar the temperature of the liquid and thus the flange can be lowered to 1.8 K, i.e. superfluid He.

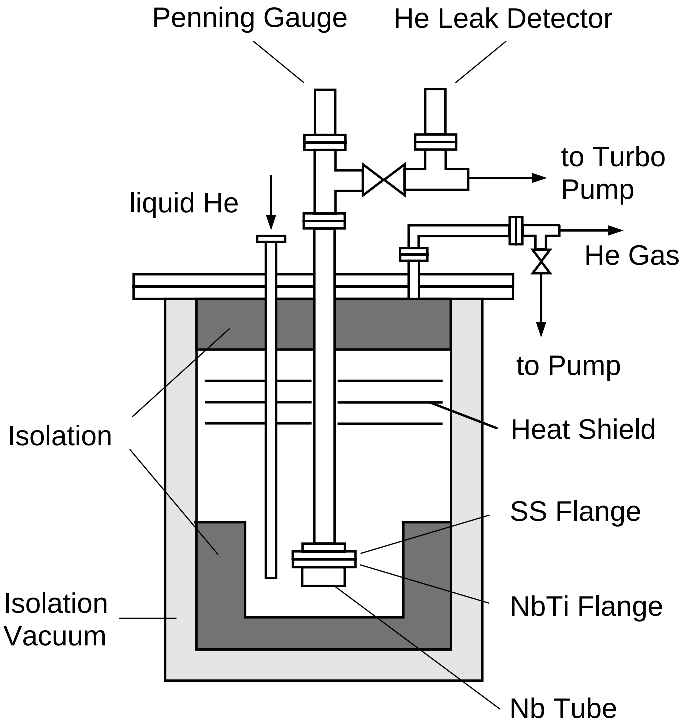

Figure 4: Schematic drawing of the experimental set-up used for the cold tests of the flanges.

NbTi flanges of various sizes as well as a NbTi-Nb connection made by electron beam welding have been tested using various types of massive gaskets: standard Cu conflat gaskets, heat treated Cu conflat gaskets, Al conflat gaskets and Al wires. For the conflat gaskets the flanges were machined with the standard conflat flange geometry having a knife edge. For the aluminum wires a groove was cut into the flanges.

After a leak check of the connection at room temperature several cycles were made between room temperature and 4 K. Afterwards the gasket was exchanged and the whole test repeated. In addition some flanges have been tested down to temperatures of 1.8 K using superfluid He.

At room temperature the measured leak rates are below 10^{-10} mbar l/s for all type of gaskets. With the flange immersed in liquid or superfluid He the leak rate for all flange connections sealed by aluminum wires stay below 10^{-9} mbar l/s. In contradiction for all types of conflat gaskets significant leak rates of up to 10^{-6} mbar l/s have been observed accompanied by damaging of the knife edge. This behavior can be explained by the different thermal expansion coefficients for NbTi, stainless steel and the conflat gaskets.

Based on the results of the cold tests the aluminum wire gasket has been chosen for the new flange design. The measured leak rate of the cold flange is sufficiently low for the performance tests of the TESLA/TTF cavities in a vertical cryostat. For the final cavities to be installed into the linac, which are welded into a titanium tank as shown in fig. 1, a much lower leak rate can be expected as the flanges are no longer surrounded by liquid helium but by the isolation vacuum which is of the order of 10^{-6} mbar.

5 Summary

The new flange design for the superconducting cavities for TESLA /TTF is based on niobium-titanium flanges, which are electron beam welded to the niobium cavities. Massive aluminum wires are used as gaskets. These new flanges fulfill the necessary requirements of the flange connections: All parts can be cleaned to class 10 level. The high temperature treatment at 1400°C does not weaken the mechanical stability of the flanges. The contamination rate by particles during the assembly of the cavities is substantially lower than for the present design. The flange connections are UHV-tight at room temperature and superfluid He. The new series of TTF cavities presently under fabrication will be equipped with the new flanges.

Acknowledgment

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References

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