1.3 GHz Cavity Weld to Helium Vessel

A. Schmidt, A. Matheisen
DESY, Notkestraße 85, 22607 Hamburg, Germany

Abstract

At DESY Hamburg superconducting accelerator units are under development for the FLASH and the XFEL Projects. (fig.1). Nine cell superconduction accelerator structures, also named cavities, with 1.3 GHz resonance frequency are made from Niobium sheet material by industrial partners. Those cavities are cooled by bath cooling with Helium at a temperature of 2K. For accelerator application each cavity is equipped with an individual helium vessel and is connected to a central feed in line and a gas return pipe of 300 mm inner diameter [1]. To get the acceleration gradient as high as possible, the cavities have to undergo various preparation steps [2]. During the last decades significant improvements on acceleration gradients are made.

Fig. 1: 1.3GHz nine cell Cavity

The improvements of cavity characteristics like gradient and quality factors require improvements on the subsequent following processes of completion of helium tank and module assembly techniques as well. An overview on the sequences and processes for tank installation for the DESY 1.3 GHz resonators will be given.

Introduction

Improvements on acceleration gradients were made during the last 15 years of development. The gradients of cavities in the frequency range of 1-2 GHz are raised from 5 MV/m in the 1990th to more then 30 MV/m with today's preparation and fabrication technique. In the actual design of the DESY cryounit (module), 8 resonators one superconducting quadrupole and one beam position monitor are installed into a common vacuum vessel [1].

The nine resonant cells of a cavity are surrounded by an individual bath cryostat called He tank (fig.2) [3], while the inter-connections from cavity to cavity (beam pipes) are located in the isolation vacuum and cooled by heat conductivity of the niobium walls. The eight separated tanks and the superconducting quadrupole are connected via chimneys on top of each He tank to a common 2 K two phase helium distribution line [4].

After fabrication and preparation each cavity undergoes an acceptance test in a vertical cryostat where it is immersed in a liquid He bath at 2 K. After successful passing the acceptance test, the tank, serving as He bath for the cells in module application, has to be welded to the cavity without influencing the cavity characteristics. The tanks are made from Titanium. The conical discs are made out of a titanium-niobium alloy (Ti52Nb48) servers as connecting element between cavity body and He vessel elements. They are welded to the cavity during the cavity fabrication.

The interconnection from the TiNb alloy of the conic disc to Ti elements of the He vessel has to be weld by the electron beam welding [5]. All other joints of the helium vessel are interconnections from Titanium to Titanium and can be made by the TIG welding.

Fig. 2: Helium vessel and parts

After completion of the tank the access to the cavity body is limited. Therefore one major requirement of the tank welding process, beside the leak tightness and cold pressure resistance of the welds, is the preservation of the cavity characteristics like the geometry, the field flatness, the frequency, the acceleration gradient and the quality factor Qo [6].

In parallel to new techniques to reach for higher gradients [2] it is always necessary to improve all steps for cavity completion and module assembly as well. It was shown on several resonators, installed into modules of the FLASH accelerator, that for the He tank welding the procedure and parameters in use and described here, do not influence any of the resonators characteristics.

Tank welding process

1. Cavity assembly for vessel welding

1.1 The aim of the FMS

The preparation of super conducting resonators is done under clean room conditions which are classified as ASTM class 10 (ISO 4) quality. All processes for He tank welding are done in work shop areas that can not fulfill the cleanliness required for conservation of the cavity inner surface. Furthermore the frequency of the cavity at room temperature needs to be adjusted to less then 100 KHz deviation from the nominal frequency. For accelerator application the parallel excitation of the nine individual cells, the field profile, has to be better then 90% [6]. During the welding process a control of these parameters and the accessibility to the cells for tuning, if needed, has to be made possible. To meet all this requirements a field profile measuring system (FMS) (fig.3) is developed.

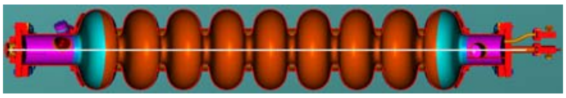

Fig. 3: Cavity with field profile measuring system installed

1.2 FMS set up

The FMS set up consists of two stainless steel flanges equipped with a fixed RF antenna each. The flanges are connected to each other by a Teflon tube located on the beam axis of the cavity. One flanges holds two vacuum valves (fig.4), the second flange is equipped with a cap that closes the volume of the Teflon tube on the other side (fig.5). The valves arrangement allows parallel pumping of the volumes (Cavity and Teflon tube) to perform in depended leak checks of the two separated volumes.

A bead pull body can be installed inside this tube. This arrangement guides the bead pull on the beam axis and guaranties that RF measurements can be done at any time without particle contamination to the cavity, appear during movement of the bead pull.

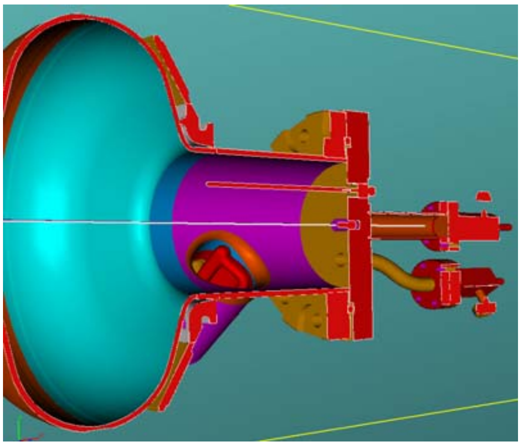

Fig. 4: FMS on short cavity side with two valves, RF antenna and Teflon tube

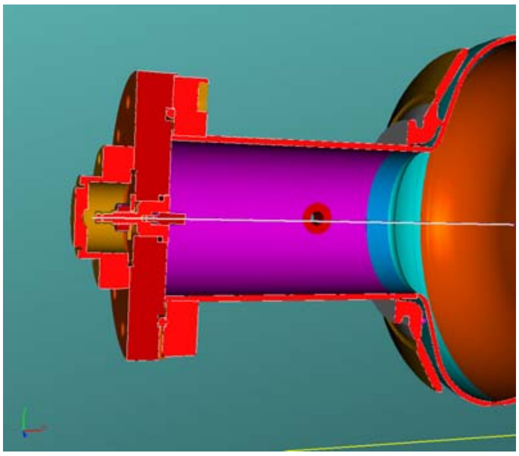

Fig.5: FMS on long cavity side with Teflon tube clamping

During the tank welding process the cavities reach temperatures of 60 to 100 °C. To make sure that no contamination of the cavity will occur by evaporation of gasses by the FMS, the adsorptions of the Teflon tube was measured and verified [7].

1.3 FMS handling

The installation of the FMS is done in a class 10 clean room. After the vertical test only the beam tube flanges need to be opened to install the FMS, all other flanges and couplers stay as measured. Before leaving the cleanroom all flanges and the Teflon tube have to be checked by a Helium leak check. After this leak check the cavity and the Teflon tube are refilled with ultra pure and particle free argon to normal pressure.

2. Tuning and frequency control

For tuning of the cavity, the valve, located on the cavity axis and the cab have to be removed. The RF antennas are connected to a generator for frequency measurement. For a field profile measurement the bead pull body is pulled through the cavity on the axis defined by the Teflon tube. The cavity remains protected against any contamination during these manipulations due to the separation by the Teflon tube.

The arrangement of the FMS flanges allows full access to all cells and the conic disc for tuning of the cells. Beside the frequency and field flatness, the conic disc has to be adjusted as well.

The conical discs with the bellows and the reduction ring on place slide into the He vessel tube. Any misalignment of these units leads to a cavity deformation when the cavity body is inserted into the helium vessel tube.

After tuning and adjustment, the FMS is closed again by the valve and the cap. To minimize risk in case of a failure in the Teflon tube the valve, the cap and the Teflon tube are purged with Argon again to minimize oxygen in the cavity.

3. Electron beam weld of conic discs

3.1 Assembly of bellow and reduction ring

Before electron beam welding the conical discs and the edges of the joint have to be well cleaned. An etching by acid is not required. The bellows, located on the cavity long beam tube side (fig.6) and the reduction ring are assembled with fixtures (fig.7) to the cavity. These fixtures fix the parts tightly together and serve at the same time as a guiding bearing to unreel the cavity in the EB welding fixture during weld process.

Titanium shields are inserted between end cells and conical disc to protect the cavity against evaporations and thermal radiation during welding (fig.7).

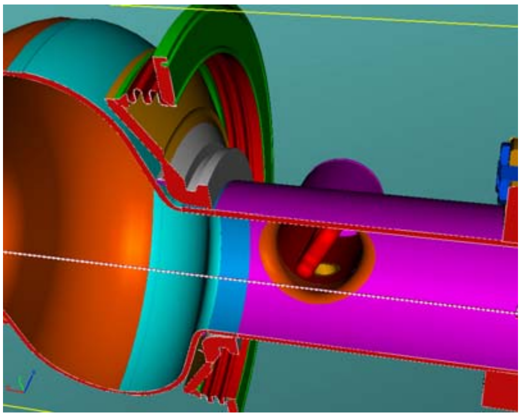

Fig. 6: Cavity long beam tube side with bellow

Fig. 7: Cavity long beam pipe side with bellow, fixture and shield on place

3.2. Electron beam weld 1/2

Electron beam welding is done at a vacuum pressure below 1Exp-4 mbar. The cavity is filled with ultra pure argon at normal pressure and tends to elongate due to the pressure difference building up in the EB welding chamber. The EB welding tool fixes the cavity tightly and takes all forces, coming from the pressure differences between cavity and exterior pressure.

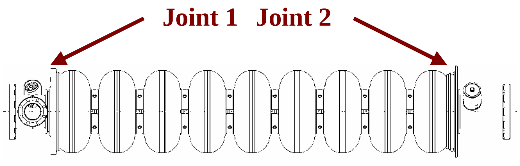

Fig. 8: Weld sequences at electron beam welding

For welding of joint 1 and 2 (fig.8) identical weld parameters can be applied. These welds are done in two phases. In the first pass a deep penetration weld, is be done by a “hard” electron beam and a fast rotation velocity of the cavity. In the second pass a cosmetic seam is done by a soft beam that oscillates itself in the range of KHz. Figure 9 shows a typical micro cut of a weld done with the two phases weld sequence.

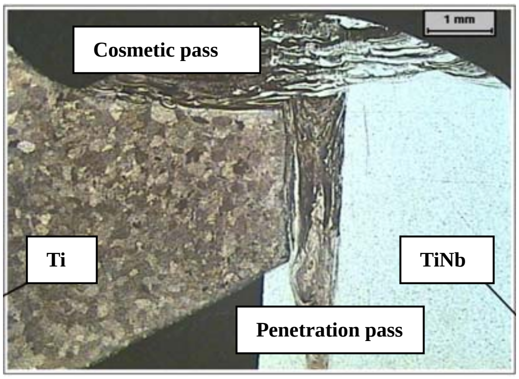

Fig. 9: Polished micro cut of Titanium-Niobium to Titanium electron beam weld

The layout of the EB welding chamber in use does not allow welding both joints in one pump down cycle. To prevent oxidation of the niobium during installation for the second weld the cavity must cool down to 60 °C and below before venting the vacuum chamber.

3.3 Final control

After welding of the bellows and the reduction ring to the conical disc the fixtures are removed. Both welds have to be leak checked. To perform the leak test a container is installed and evacuated on each side. This container covers the beam tube while the weld joint have full accessibility at normal pressure for the helium leak check (Fig.10). The frequency and field flatness are controlled and tuned again if necessary after the leak check.

Fig.10: Cavity with leak check container

4. TIG weld 3/4/5/6

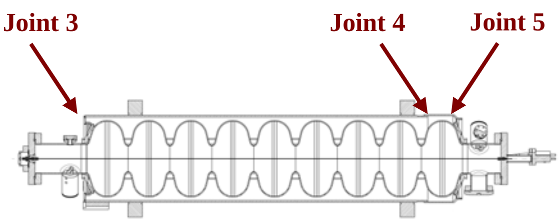

Fig. 11: Weld sequences at TIG welding the Helium vessel

The connecting joint welds of the titanium vessel tube and the sliding collar are done by orbital TIG welding under inert gas atmosphere. A cabin is designed and allows reducing oxygen content of the atmosphere down to below 20 ppm. An integrated weld nozzle holder is designed to get easy access to the joints (fig.12).

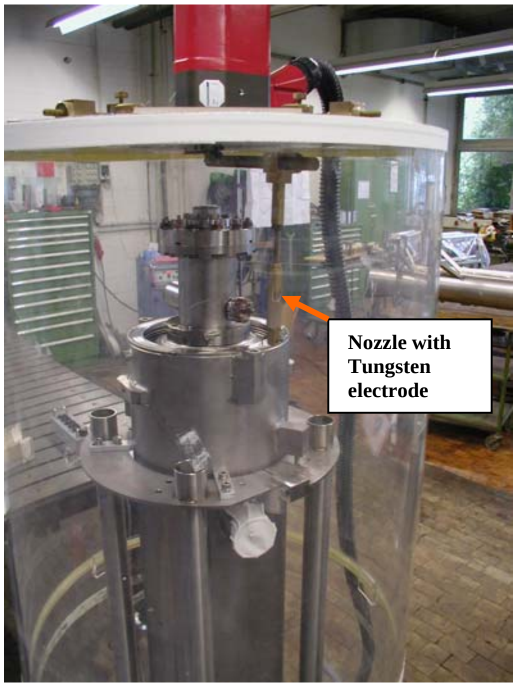

Fig. 12: Cavity installed in a welding cabin rinsed with argon

All operations during He vessel handling have to be done with special care to prevent geometry changes of the cavity that lead to a “bana-shape” of the resonators or field profile and frequency displacements. Errors occurring at that point of production can not be corrected without cutting away the He vessel tube.

Due to the required stiffness of the tank necessary for pulsed operation and high gradient cavities (Lorenz force detuning) the tank design does not fore see elastic elements and the shrinkage of the material during welding will be transferred to the cavity. An exact knowledge of the shrinkage of each weld was necessary and was studied to design tools and adopt sequences, preventing the deformation of the cavities.

It was found that joint no 4 shows the largest shrinkage. To allow shrinkage with out forces on the cavity, the joint 5 is not tacked and acts as a sliding connection. While tacking and welding joint 4 the vessel can slide on the cavity reduction ring.

Because of studying the shrinkage the fixtures could be optimized in a way that there is no misalignment on joint 5.

4.1 Alignment

Inside the module the cavities are aligned by bearings, acting on the brackets, welded to the He vessel. In addition the cavities are connected to each other via bellow elements. The rotational orientation of the cavity can not be corrected after the bellow elements are installed. For installation of the power coupler warm part after insertion of the cold mass into the vacuum tank, a defined orientation of the power coupler port in respect to the vacuum vessels and the bearings is required.

The position of the power coupler in respect to the tank brackets is fixed as soon as the He vessel tube is welded to the cavity. To ensure a precise orientation of power coupler port and tank brackets a fixture for tack welding is developed.

The tank is inserted into a horizontal fixture where the brackets are fixed in position. In addition this fixture allows a precise positioning of the power coupler post as well. After this tank alignment the cavity is inserted into the He tank. The cavity can be turned until the power coupler flange rests on the positioning post (fig.13).

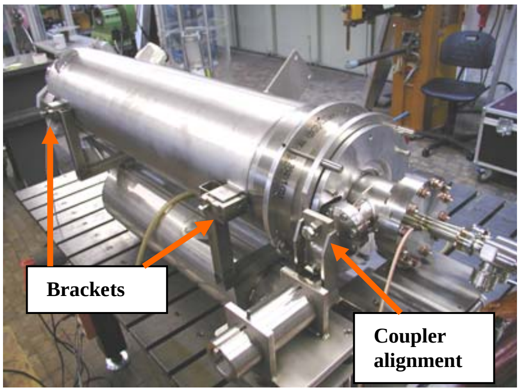

Fig.13: Alignment Fixture for cavity to vessel

4.2 Tack weld

The joints No.3 (fig.14) and No. 4 (fig.15) are manually tack welded inside this fixture in horizontal position while joint No. 5 is not fixed at that time.

During tack welding the inner side of the tank is purged with argon.

4.3 Weld 3

After tack welding the tank is assembled in a handling frame and is oriented vertically into the welding cabin. The orbital arm with the tungsten electrode is mounted and adjusted for orbital welding of joint No 3 (fig.12). After welding this position, the bellows is fixed by clamps for the next weld operation. To arrange for joint 4 weld the cavity is turned head over top.

Fig. 14: Tacking bellow side / Joint 3

4.4 Weld 4

The production of the He tank tube resulted in some oval shape of the tank which leads to a gap between tank tube and connected sliding collar. The weld nozzle for joint 4 has a special holder, designed in a way that the electrode is always guided parallel to the weld seam, independent of the roundness of the tank tube in use.

Weld No 4 leads to the larges shrinkage during the tank welding procedure. This shrinkage is taken and compensated by displacement of the sliding collar tube at the position of weld No 5. This connection is designed as a sliding unit, free of forces on the cavity.

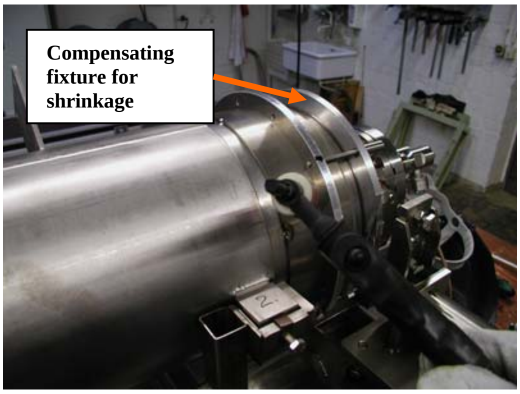

Fig. 15: Tacking and adjusting sliding collar / Joint 4

4.5 Weld 5

After welding joint 4, joint 5 will be tacked and finally welded. Even this weld results in a minimum of shrinkage transferred to the cavity. This displacement deforms the cavity elastically. This compression on the cavity is removed by turning the cavity back to horizontal position and removing the bellows camps. The cavity expands to a force free position where the bellows is at the regulate position. The clamps are connected again and fixed in this neutral position.

4.6 Weld 6

The rotational cavity alignment within the cavity string is done by alignment of the brackets on the helium vessel. The design of the modules foresees fixed position of the power coupler. This position is given by an adapter welded onto the sliding collar.

The last step of the tank welding process is to weld this adapter on the sliding collar. Therefore the cavity with tank is brought back in the horizontal alignment and tack fixture and a holder with the adapter is installed (fig.16). After precise alignment of the adapter the weld connection between adapter and sliding collar is done manually, while the inside of the he tank is flushed with inert gas.

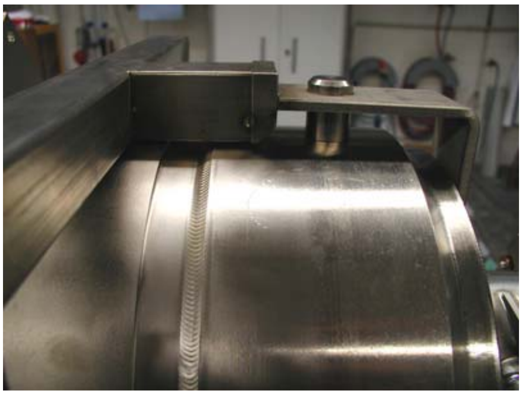

Fig. 16: Adapter on sliding collar

5. Final operations

After all seams are welded and brushed, a final vacuum leak check of the whole tank unit and a frequency control is done.

After this final quality control the cavity exterior is cleaned to class 10 quality cleanliness and the cavity enters the cleanroom again. The FMS is disassembled inside of a class 10 cleanroom area. Due to the usage of the FMS during tank welding, the following up cavity preparation steps for horizontal

RF test and module assembly, can be done without additional chemical treatments required.

Conclusion

A total of more than 70 cavities have been successfully welded into He vessels and installed in modules, operating in the flash linear accelerator at DESY. The latest changes in He vessel welding process took place in the 2006. After this changes twelve cavities, with acceleration gradients of more than 30MeV/m have undergone the tank welding process. All those cavities do not show variances in field profile, resonance frequency or gradients in respect to the vertical measurements during the horizontal test. Some of these cavities are installed into module 6 which has undergone various test and warm cold cycles in the CMTB at DESY [8]. They will be operated in FLASH after the shut down of 2007.

Outlook

At DESY a cost-saving alternative to the expensive electron beam welded of the bellows and reduction rings is under development. In future bellows and reduction rings welding might be performed by the TIG welding as well. This option does not require an EB welding machine during industrial production and could bring significant cost savings due to the lower investments. First experiments of Titan-Niobium and Titan TIG welding have shown promising results on micro cuts [5].

Acknowledgment

Special acknowledgment has to be given to R. Bandelmann for his constructive support on design of fixtures, the Lufthansa Technik in Hamburg and the DESY group ZM31 for their execution of welds and their personal support. Special thanks have to be given to G. Kreps, W. Menck for their support to optimize the procedure.

References

[1] XFEL technical design report DESY 2006-XXX July 2006 ISN 3-935702-17-5 Chapter 4.2

[2] Preparation Sequences for Electro-Polished High Gradient Multi-Cell Cavities at DESY, A. Matheisen proceedings of the SRF workshop 2005 Ithaca NY USA THP 08

[3] XFEL technical design report DESY 2006-XXX July 2006 ISN 3-935702-17-5 Chapter 4.2.2.3

[4] XFEL technical design report DESY 2006-XXX July 2006 ISN 3-935702-17-5 Chapter 4.2.2.4

[5] W. Singer, J. Dicke, G. Weichert private communication

[6] D. Proch, G. Kreps private communication

[7] DESY MVP note 04/03 Hamburg Germany;
Z.Sandok und J.Wojtkiewicz Desorptionsmessungen an Teflonschläuchen.

[8] Summary Module 6 Tests on CMTB, L.Lilje et all. XFEL project meeting No. 146; April 4th 2007 DESY