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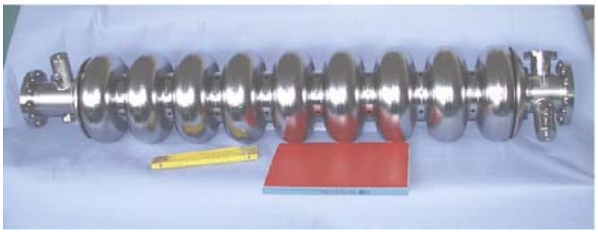

Deliverable 2.3.3.6:

EB welding of prototype components

V. Fonseca-Sousa, D. Proch, A. Schmidt, J. Tiessen, D. Vermeulen

DESY, Hamburg

Abstract

The electron beam (EB) welding installation at DESY was used to weld single cell and multicell Niobium cavities. Welding parameters for the different welds on a cavity were explored, tools and fixtures for the welding were designed and built. A series of single cells was fabricated to qualify new Niobium vendor or to measure the performance of new Niobium (large grain and single crystal instead of small grain material). Multicell cavities were welded, mainly to exchange the old flanged by a new design. Finally the preparation sequence of welding parts was modified to streamline the series fabrication of multicell Nb resonators.

Acknowledgement

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395).

1. Introduction

The standard fabrication of superconducting accelerating cavities consists of
- production of polycrystalline Niobium sheets
- forming of cups
- Electron beam welding (EB) of cells
- fabrication and EB welding of additional parts, e.g. Higher Order Mode (HOM) couplers
- surface treatment by chemical- or electro-polishing, cleaning by high pressure water and assembly in a class 10- 100 clean room

EB welding is a very critical fabrication procedure:
- The inner weld surface should be smooth
- The weld should completely penetrate the material without any gaps or cracks
- The weld region should not have any inclusions of non Niobium material
- The thermal conductivity of the Niobium material should not be degraded. This requires extreme good static and dynamic vacuum conditions.
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There are industrial EB welding installations available, but the required high quality of clean conditions and extreme vacuum is in most cases difficult to be met. Furthermore it is not easy to establish a fast prototype production by orders to industry. Therefore several accelerator laboratories use specialized in house EB welding machines for R&D or prototype developments of superconducting Niobium cavities. DESY has invested in such an EB welder. The vacuum system was design to reach extreme good performance. Furthermore the EB welding installation should allow a fast prototype production of single cells.

The main tasks of the DESY welding machine are:
- To explore the benefit of Niobium cavity welding under extreme low vacuum conditions
- To qualify cleaning treatments of Niobium material before welding
- To optimize the welding parameters for the typical EB welds of a superconducting accelerator design like TTF or XFEL shape
- To produce single cell cavities for qualification of new Niobium vendors
- To produce single cavities from new Niobium material like large grain or single crystal material
- To fabricate multi-cell cavities

2. Technical description of the EB welding installation at DESY

Principle:	Triode system with direct heated cathode of tungsten and quick change system
High voltage:	up to 150 KV
Beam power:	max. 15 kW
Beam current:	0 up to 100 mA
Lenses current (Focus):	1 up to 3 A

Beam deflection angle:	up to 5°	
Cubic Measures:	3300mm × 1400mm × 1600mm (approx. 7.4 m^3)	
Chambers material:	1.4435	
Vacuum:	> $5x10^{-6}$ mbar (approx. $2x10^{-8}$ mbar)	
Pump down time:	approx.: 20 min =$3x10^{-6}$ mbar	
Pumping speed:	First roots pump	approx. 1000 m^3/h
	Second roots pump	approx. 250 m^3/h
	Dry fore pumps	approx. 160 m3/h
	Interstage pumping	approx. 40 m3/h
	2 cryo-pumps Coolvac 10.011	approx. 2 × 10.000 l/s
	Dry fore pump	approx. 40 m^3/h
	2 turbo pumps	approx. 2 × 1050 l/s
Hinge:	Hinge with a three phase synchronic motor in high vacuum	
	Maximum torque 100Nm	
	Nominal rotation speed 30U/min	
Traverse path.:	Outside synchronic motor	
	1400 mm	
Cross path:	Interstage vacuum synchronic motor	
	400 mm	
Traverse table:	length 1500 mm	

Table 1: Technical Data of the “DESY” Electron-Beam-Welding-Machine

Figure 1: EB installation at DESY

Technical details of the DESY EB welding machine are listed in table 1. A picture of the welding machine is shown in Fig.:1. The DESY welding machine has several special components which are designed to establish extra-ordinary low static and dynamic vacuum conditions. These components are listed in table 2.

Special care has been taken in designing the vacuum chamber:

- all movable parts have been lubricated by a special vacuum grease
- the inner parts of the chamber consist of UHV compatible material, e.g. stainless steel, pure copper and aluminum.
- the geometry of the inside of the chamber is constructed

Company	Unit	Application
Steigerwald	Power station SINCOS	mover for Y-axis
Steigerwald	Modem	Internet connection for SAPS
Steigerwald	Splice detector,_manuell	CNC-controll
Leybold	Maintenance box, cryo-unit	Repair of compressor
hightec	N2 line of stainless steel	Venting
Busch	Vacuum pump Typ RC 0010 B	local vacuum at Y-mover
Zoller	3 phase transformer	Power supply Y-mover
Dehn	fast valve	pressure protection
BOC Edwards	Scrollpump XDS35i	course vacuum gun
Warmbier	Simco TopGun3	Cleaning of components
ELV Elektronik	Grand X-Guard	Documentation of melt
VAT	All metal valve	valve for residual gas analysis
Kelvin	Transportation box	Storage of etched Nb parts
BDK	Laminar-Flow unit Type RK	Clean room for assembly
Wittenstein	ESAI Servo-unit	positioning unit
Wittenstein	Vacuum motor	mover for Y-axis
PINK	assembly platform in vacuum	Motor in vacuum
Bautz	Servomotor M406F	Motor Y-mover

Table 2: List of special components of the DESY EB welding machine.

3. Investigation of Niobium thermal conductivity as function of welding vacuum

The thermal conductivity of the Niobium material is crucial for superconducting RF application. A local defect on the inner RF surface will produce heat. This results in an increase of superconducting losses because of the temperature dependant BCS surface resistant. At a certain level this will initiate a thermal run-away so that the cavity will quench. Therefore a high thermal conductivity of the Niobium is favorable.

For easy measurement the RRR value (residual resistance ratio) of the sample Niobium is determined rather than the thermal conductivity. Both values are correlated. A RRR value around 300 is the standard specification of Niobium for cavity fabrication [1]

Fig 2:Example of Nb welding strip
(about 40x120mm^2)

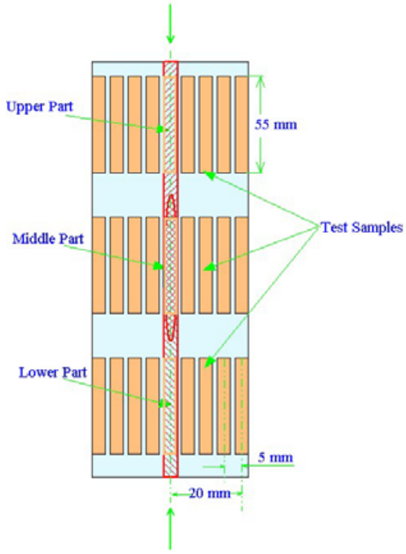

Fig 3:Scheme of the RRR samples cut off

Sample strips of Niobium are used to measure the degradation of the RRR value. Figure 2 shows the typical arrangement of such sample. After welding smaller samples are cut (see figure 3) and the RRR value is measured by cooling to 4.5 K and resistance measurement by 4 probe technique. Figures 4 and figure 5 show the data from two companies. In each case the (static) welding pressure was varied by two orders of magnitude. The data were taken at the welding seam and also 20 mm away from the weld. Both measurements conclude, that a static vacuum at the lower end of 10^-5 mbar is required to avoid a degradation of the RRR value. The DESY welder can establish much better vacuum, therefore these measurements were continued at DESY to explore the benefit of further improved vacuum conditions. The result is shown in figure 6. The RRR value stays constant up to about 10^-7 mbar. Above this value RRR decreases by about 8 % at 10^-5 mbar. Therefore it can be concluded, that a value around 2x10^-5 mbar static vacuum can be accepted for Niobium cavity welding. At the present Niobium cavity fabrication technology the effort of operating a welder below 10^-5 mbar seems not worthwhile.

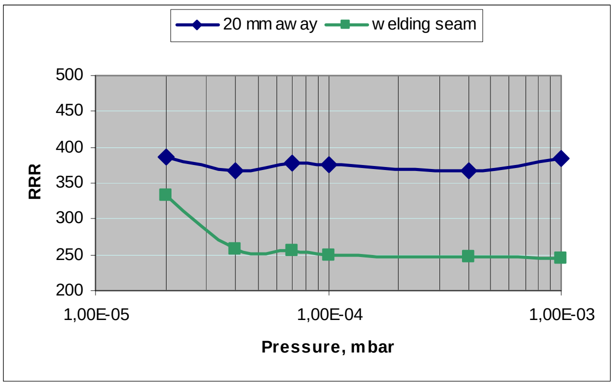

Fig.:4 RRR in the welding seam and 20 mm away versus pressure in the chamber during EB welding (company I)

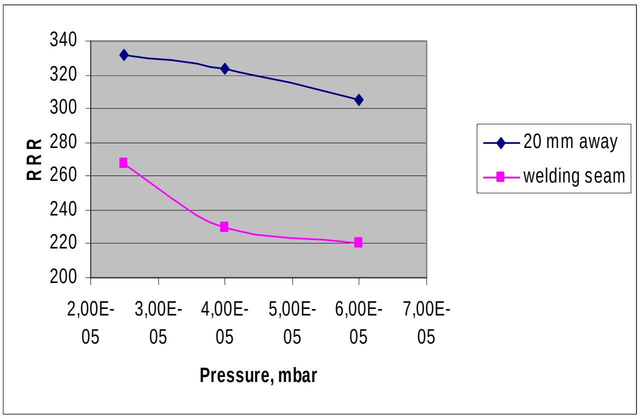

Fig.: 5 RRR in the welding seam and 20 mm away versus pressure in the chamber during EB welding (company II)

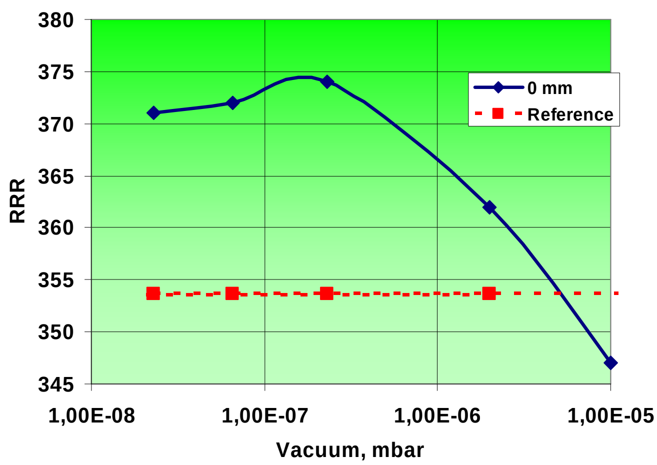

Figure 6: RRR sample measurements at the DESY welder at improved static vacuum

An interesting option is to “clean” the welder in situ just before the cavity welding. This is done by heating a separate piece of Niobium by the e-beam of the welder. The evaporated Niobium getters the residual gas so that for a short time the static vacuum is improved. The result of such procedure is demonstrated in figure 7.

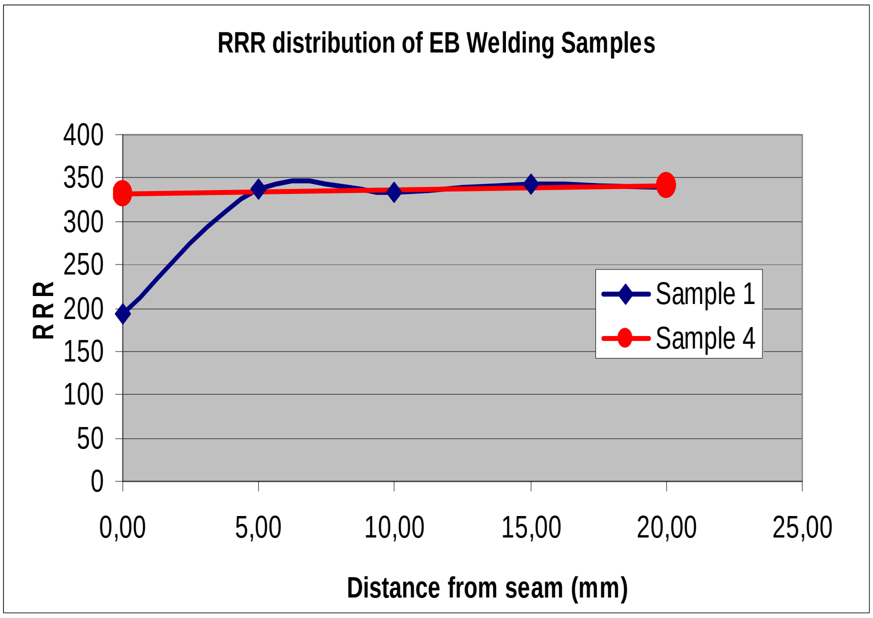

Figure 7: RRR in the welding seam area with (sample 4) and without (sample 1) of Nb evaporation in the EB chamber (DESY+Julich)

4. Single cell production

I total 23 single cell cavities have been fabricated at DESY. 19 of these cavities were made from fine grain (standard) Niobium, 4 from large grain Niobium.

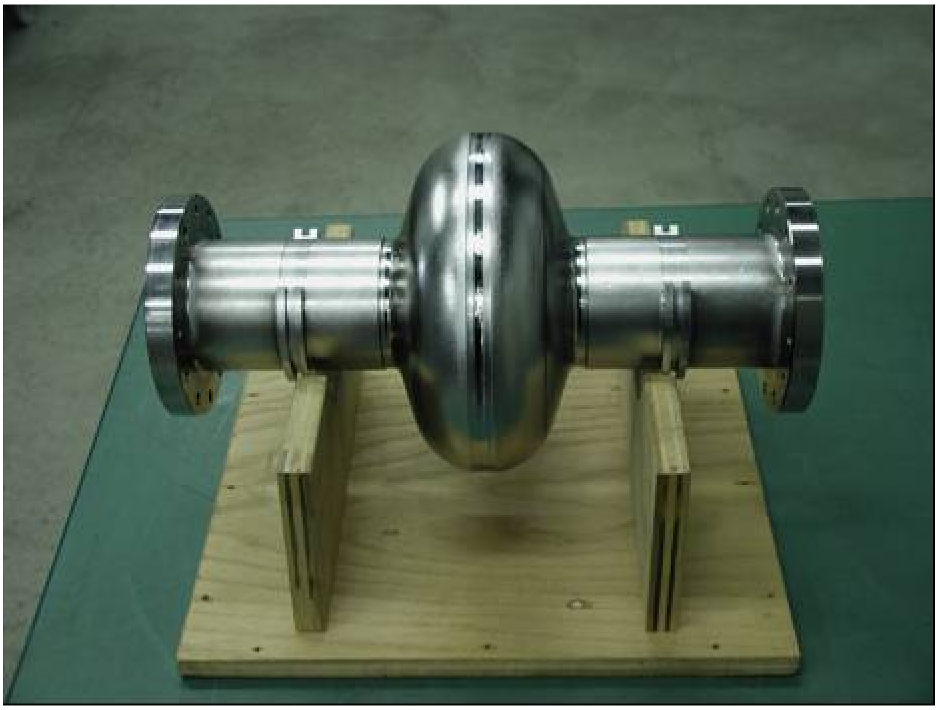

Figure 8: Standard 1-cell cavity design at 1.3 GHz (TTF shape). The flanges are of the same design as the TTF 9-cell cavity. The two sets of rings at the beam pipe serve as fixture for the mechanical support of the cavity during preparation and cold test.

These 23 single cell cavities were used for the following purpose (the nomenclature of the cavities is "XDEY", were X stands for the number of cells, DE stays for DESY as manufacturer and Y is the fabrication number of the cavity):

- Three cavities were made from Heraeus / Plansee Niobium in order to qualify this new vendor; In the past the Heraeus production covered Niobium melting as well as sheet production. In the new consortium Plansee takes care of the fabrication activities after the melting procedure. (1DE14 – 1DE16)
- Three cavities were made from fine grain Ningxia material to qualify this new Chinese vendor. (1DE17 – 1DE19)
- Three cavities were fabricated from Russian vendor Giredmet. This material has a RRR value up to 600. (1DE4 – 1DE6)

- Two cavities were fabricated from Cabot Niobium material. This material has a low RRR value of 230 only. (1DE 12- 1DE13)
- Three cavities were fabricated using well-known Heraeus material in order to establish the cavity fabrication at DESY. (1DE1 – 1DE3)
- Five cavities were fabricated in order to investigate + optimize the weld preparation sequence. (1DE7 – 1DE11)
- Two cavities were made from large grain Niobium (Heraeus) to explore the performance of this material. (1DE20 – 1DE21)
- One cavity was made from large grain Niobium (NPC) in order to explore the performance of this material. (1DE26)
- One cavity was fabricated as a mechanical dummy in order to test the properties of the modified beam-tube flange for XFEL cavities. (1DE27)
- In addition, one Nb gun single-cell cavity and one Nb gun two-cell cavity have been fabricated

The fabrication of the cavities 1DE22 to 1DE 25 could not be finished because of material problems

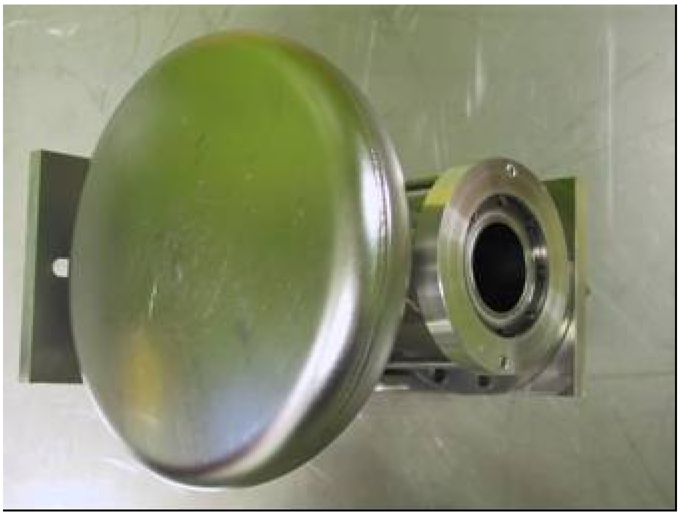

Figure 9: Picture of a one cell RF gun cavity (phase velocity of 0,6)

Several welding tools were designed and fabricated for the EB welding operation of single cell cavities: equator welding, beam pipe to cell welding, flange welding (beam pipe flange and pick up flanges. Two of such tools are shown in figure 10 and figure 11.

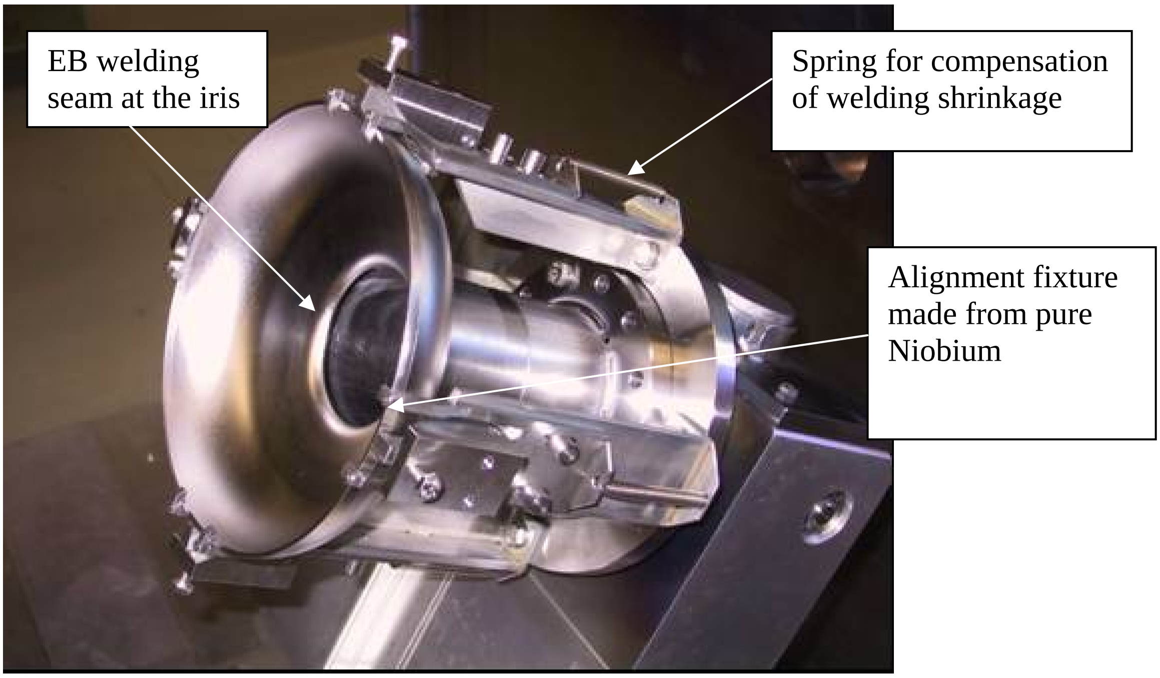

Figure 10: Welding tool for the cell to beam pipe connection

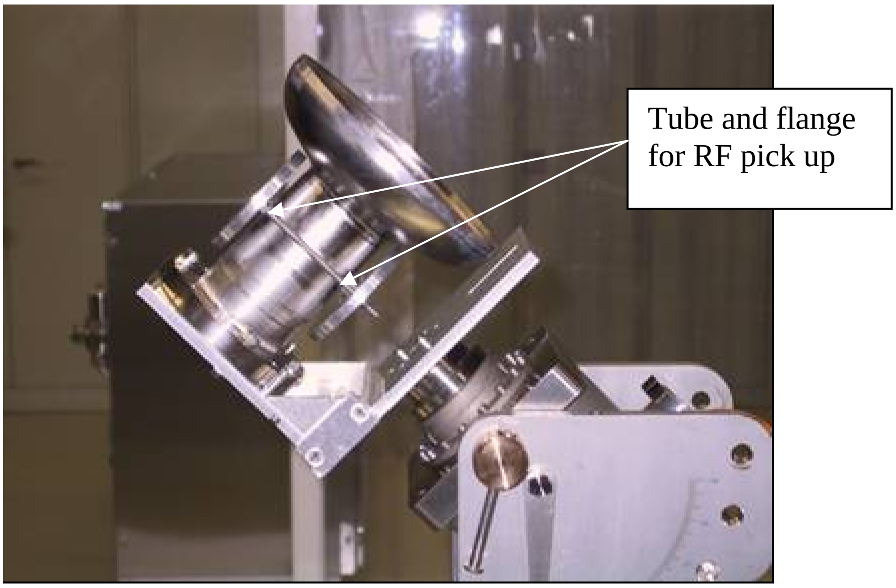

Figure 11: Welding tool for the flange welding at the pick up signal line

5. Multicell cavity production

The DESY EB welding facility was also used for welding 9-cell cavities. The inner space of the welder, however, is limited so that a horizontal placement of the 9-cell cavity was not possible. Therefore it was necessary to design and build a complicated tilted welding support. With this arrangement several 9-cell cavities were welded. Amongst those were 9 cavities of the early CERCA production (C21 to C28). These cavities had flanges of the old TTF design (pure Niobium sealing technique). A more reliable design was developed later. The flange is made from NbTi and is welded to the beam pipe. In cooperation with ACCEL Company a repair technique was developed and all 9 CERCA cavities were repaired accordingly.

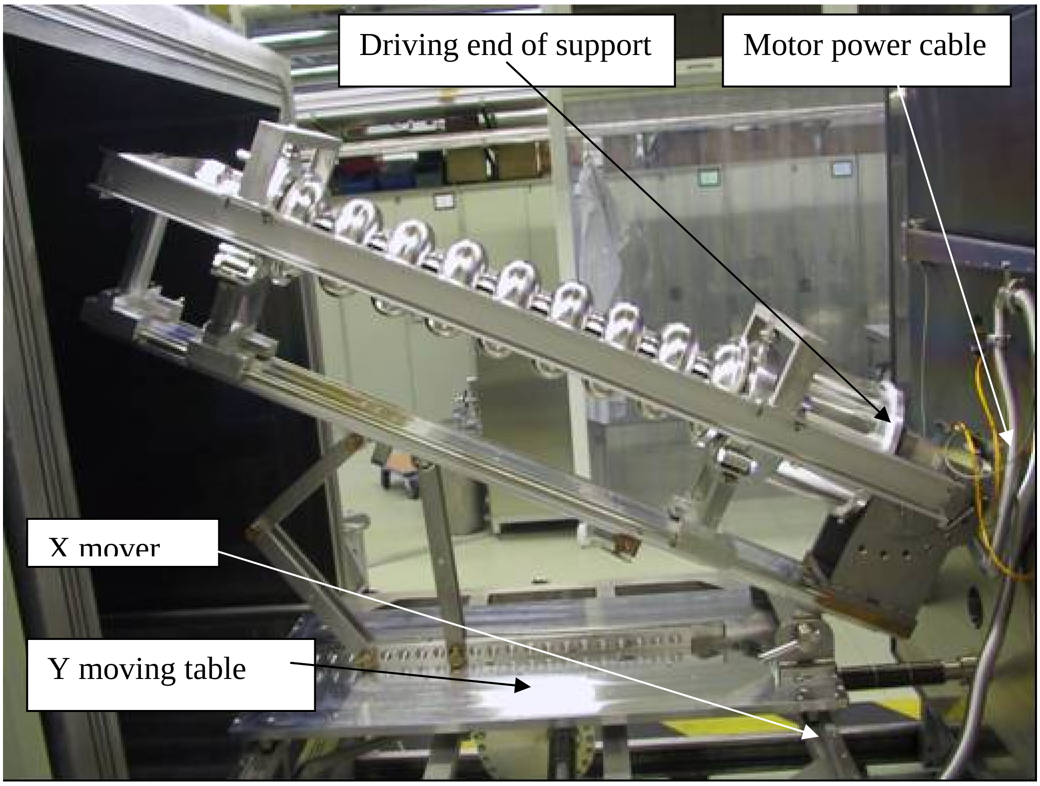

Figure 12: Complete support for 9-cell cavity welding at the DESY EB facility

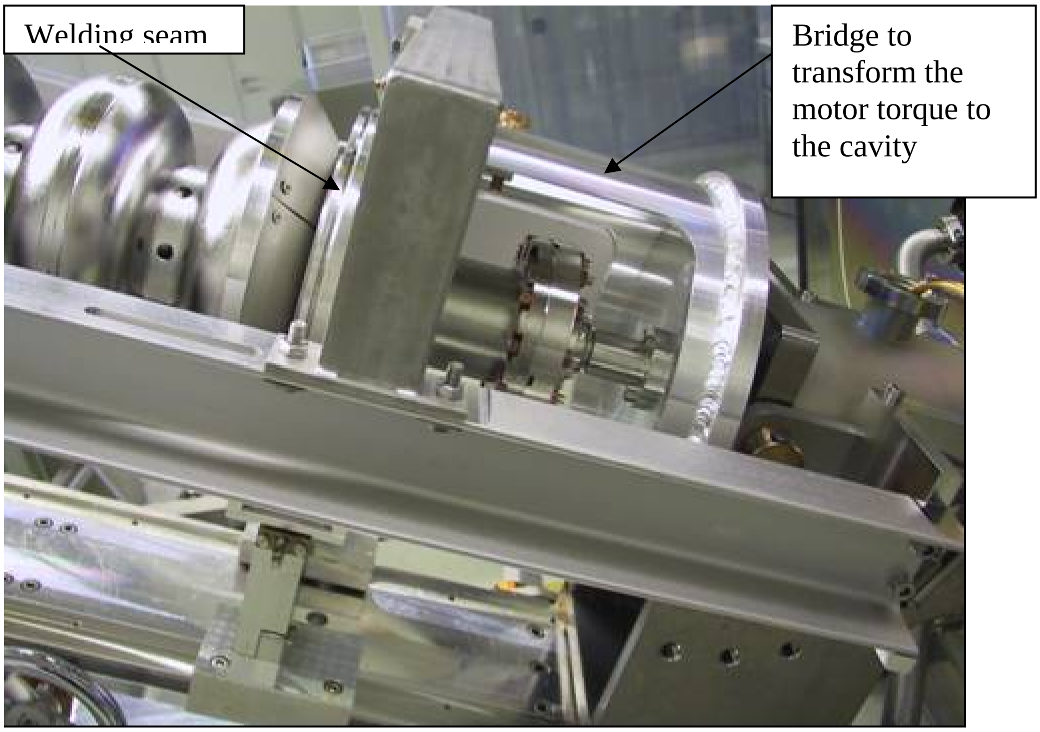

Figure 13: Details of the driving end of the welding fixture for multicell cavities. In this picture the EB weld at the outer end of the conical head disc is performed.

Figure 14: Welding fixture for the exchange of the older Niobium flange system with the new NbTi design.

6. Further activities with the DESY EB facility

It should be noted that the DESY EB facility was not only used to weld single and multicell cavities. Also repair procedures for a “damaged” cavity (e.g. burned hole at the equator weld) were investigated. More important were the validation of cleaning recipes for welding parts, especially under the aspect of series production of cavities for the XFEL project. One example is the old specification of finishing the cleaning and welding action of Niobium parts within 8 hours. The suspicion was that oxide formation over a longer time on the surface of Niobium might result in bad superconducting properties. Several cleaning treatment have been carried out with single cell cavities and the following superconducting tests could validate the best procedure. The concluded best procedure is to 1, chemical clean the parts by the standard BCP method, 2, rinse with water, 3, transport into a clean-room, 4, rinse thoroughly with high purity water and 5, store in a container either under vacuum or under clean dry nitrogen. A storage time of up to one week did not show any degradation of superconducting properties.

7 Conclusion

The DESY EB welding installation was designed to investigate optimum welding parameters for Niobium cavities. It is concluded that vacuum conditions in the lower range of 10^-5 are sufficient not to reduce the RRR value of 300. Also a specification for the cleaning procedure applicable for large scale production could be defined. But mainly the EB installation at DESY was successfully used for the production of single and multicell Niobium cavities for R&D activities in the framework of the CARE project.

References

[1] Hasan Padamsee, Jens Knobloch, Tom Hays: RF Superconductivity for Accelerators, Wiley Series In Beam Physics And Accelerator Technology, ISBN 0-471-15432-6