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1.3 GHz Niobium Single-Cell Fabrication Sequence

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I. Introduction

In preparation for the European XFEL-project [1] a test programme for fabrication and preparation of single-cell niobium 1.3 GHz cavities was carried out at DESY. Main goal of the programme was the successful, to a large extent in-house fabrication of a sufficient number of cavities and to gain own experience in the complicated fabrication process. Up to now cavities have been fabricated by external firms and only the final treatment has been done by DESY.

On the one hand the cavities which were fabricated in the frame of the test programme served as qualification for additional suppliers of niobium as the cavities were built from sheet material to be qualified and submitted to a proven preparation procedure. On the other hand several treatment und fabrication procedures were tested for the first time or improved, respectively. [2, 3].

II. „In-house“ Fabrication

On the basis of existing one-cell cavities initially a DESY standard one-cell cavity was constructed and a complete set of drawings generated (see II.A). The material of the half-cells is of special importance (see II.B) and was chosen according to the purpose of the one-cell cavity. In-house fabrication consists of

- The entrance inspection and scanning of the niobium sheets (see II.C.1),
- The entrance inspection of the half-cells deep-drawn by industry (see. II.C.2),
- The grinding and etching of bad spots of the half-cells (see II.C.4, II.C.3),
- Turning and milling treatment of all components, in particular treatment of iris and equator region of half-cells (see II.C.5) including subsequent shape inspection (see II.C.6) ,
- Completion by electron-beam-welding (see II.C.7).

During preparation of electron-beam welding it is essential to keep the welding seam absolutely clean. For this reason the parts to be welded are etched and rinsed beforehand (see II.C.3). Afterwards they will be transported and stocked observing the high cleanliness standard.

II.A. Construction

For the internal fabrication a set of drawings for the DESY standard one-cell cavity was generated (drawing number: 1_04_4623/0.000). The DESY standard one-cell cavity essentially consists of two half-cells and two beam tubes. The beam tubes consist of end tubes (Fig. 1, Pos. 1) with niobium/titanium flanges welded on the face side (Pos. 2). For fixture in a holding frame two mounting rings (Fig. 1, Pos. 3) are welded on the end tubes. The half-cells (Fig. 1: Pos. 4) are deep-drawn sheets that are welded with the beam tubes at the so-called iris. Finally the two half-cells are sticked together and welded at the equator (Fig. 1).

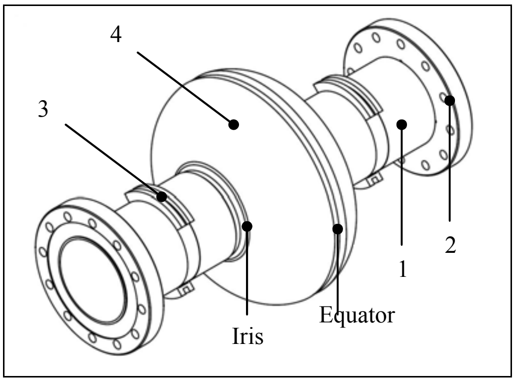


Figure 1: Cavity with position number

In order to improve possible leak search the beam tube flange with circulating notch and leak search drilling was constructed. Hence optimal leak search is made possible without generating virtual leaks. (Fig. 2) [4].

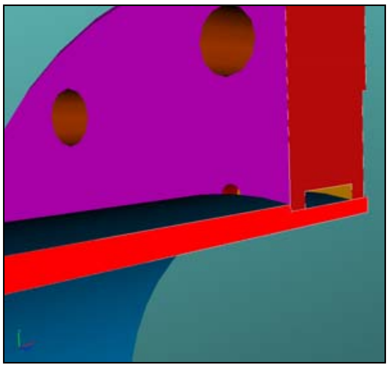


Figure 2: Beam tube with leak search notch and -drilling

The welding joint at the equator is done with a 1 mm recess in order to guarantee an exact snug fit of the half-cells during mounting. The cutting edge radius at the cutting insert of 0.4 mm was taken into account in order to guarantee a tight, gap free sticking together (Fig. 3).

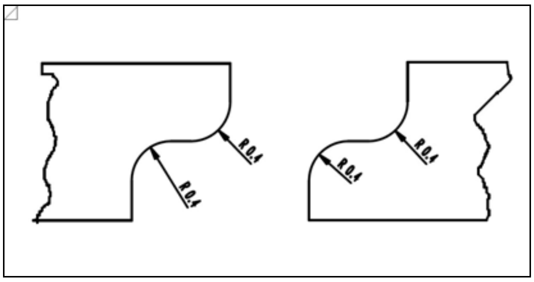


Figure 3: Contour at the equator welding joint

II.B. Material

Special attention is paid to the purity and thermal conductance of the niobium material after melting of the raw material (Ingot) and the forming of sheets, measured in the electric residual resistance ratio (RRR). During all fabrication steps purity and thermal conductance have to be maintained. Prior to processing the niobium sheets are checked for inclusions of other materials and defects (see II.C.1). For the qualification of the in-house fabrication and of the „168h rule“(see II.C.7) fine grain niobium with an RRR-value of ca 300 from the supplier Heraeus was used for the half-cells. Fine grain material from the suppliers Cabot (RRR ≈ 230), Giredmet (RRR ≈ 600), Ningxia (RRR ≈ 330) and Plansee (RRR ≈ 300) as well as large grain material from the suppliers CBMM (RRR ≈ 250), Heraeus (RRR ≈ 500) and Ningxia (RRR ≈ 450) was checked for appropriateness and quality for the fabrication of nine-cell accelerating cavities. The niobium sheets from CBMM and Cabot did not comply with the specified residual resistance ratio of RRR ≥ 300 [1]. After deep-drawing of the large grain sheets from CBMM and Ningxia substantial shape deviations of the half-cells occurred with the consequence that only one one-cell cavity could be made from four CBMM sheets and non one-cell cavity could be completed out of six Ningxia sheets.

The end tubes are made from RRR 300 niobium and can be completed either with a longitudinal weld, drawn or backwards extruded. The flanges consist of an alloy with the following component parts: 55% titanium and ca. 45% niobium. For the mounting rings niobium with RRR40 is sufficient.

II.C. Production Sequence

During the last years various firms successfully fabricated superconducting cavities. In order to comply with the specified reproducible operating gradients of 23.6 MV/m [1] for the European XFEL the production processes have to be improved constantly.

The precision and cleanliness of the half-cell processing is of crucial importance. The forming of sheets to half-cells is done by deep drawing (see II.C.2). This is the only fabrication step which cannot be done at DESY at the moment and therefore is done by qualified external firms.

For the machining processes boundary conditions were defined under which the half-cells are fabricated (see II.C.4). Even depositing of the finished parts is defined with the background that no foreign particles can enter the welding joint.

The etching processes prior to the welding are carried out according to industrial standards (see II.C.3). For the electron beam welding (EB-welding) a particular approach is necessary, too. All components are mounted in a clean room and the welding machine is dimensioned for high cleanliness demands (see II.C.7)

In the following these particular handlings are described.

II.C.1. Scanning of the Niobium Sheets

Prior to forming the sheets into half-cells the niobium is investigated for inclusions of foreign materials or defects in order to guarantee the necessary superconducting properties of the niobium. For the non-destructive and contact-free fault diagnostics the so-called high resolution „Eddy current scanning“[5] has been used successfully since many years at DESY. In the process the niobium sheet is rotating with constant speed under a fixed eddy current sensor. The reached measurement data are shown in a two dimensional figure (Fig. 4) where the deviations in terms of colour indicate bad spots and inhomogeneities.

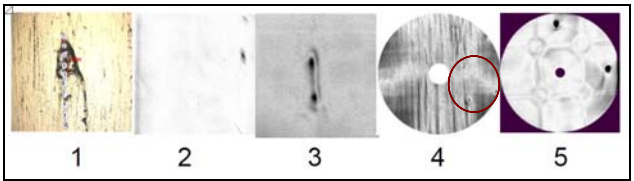


Figure 4: Various inhomogeneities in niobium sheets

1. Fe inclusion
2. Pits caused by grinding
3. Pits after milling
4. Pits caused by etching
5. Imaging of the 800°C furnace depositing and grinding traces

After introduction of this measurement several defects were detected and could be analysed. Thereby the quality of the niobium sheets production could be improved substantially in collaboration with the niobium suppliers so that today hardly any defective sheets are delivered.

II.C.2. Deep-drawing of Half-cells

The deep-drawing of half-cells is important because the accuracy of the frequency is generated in this manufacturing step. Due to comparatively high wall thickness deviations in the sheets (+/- 1mm) the deep-drawing could be harmful if stiff forming tools are used. The chosen process always allows generation of an equal shape of the inner side independent from the sheet's thickness, taking into account the given tolerance. Therefore an elastic polymer was used for the punching tool. Furthermore, the stamp has to be free from dents, blisters and scratches to avoid surface damages.
Due to the high complexity deep-drawing is still done by well-known and qualified external companies.

II.C.3. Etching

Prior to giving a cup to the mechanical processing an accurate inspection of the surface quality is necessary. That way scratches, inclusions or other mechanical defects can be identified and removed. In preparation of this the cup is etched for 40 min in an etching compound (BCP) consisting of two volume components (VC) H_3PO_4 (concentration 85%), 1 VC HNO_3 (65%) and 1VC HF (40%) at a temperature of < 23°C. The abrasion rate of fresh acid is ca. 1 µm/min. Afterwards the cup is rinsed in ultra-pure water up to a specific resistance of 16 MΩ cm.

II.C.4. Grinding of Bad Spots

If bad spots are detected during the subsequent optical inspection they may be removed with a hand grinding machine. The grinding disks in use have a synthetic, oil-resistant rubber bond which guarantees that the consumed abrasives dissolve rapidly from the disk and cannot be pushed in the material. After grinding a new etching of 20 min (≈ 20 µm) is necessary in order to remove the abrasive dust completely from the cup. Only in this way further bad spots can be identified as pores might be clogged during grinding. If more bad spots are identified grinding and subsequent etching have to be repeated.

II.C.5. Mechanical Processing

Mechanical processing of the niobium titanium alloy for beam pipe flanges is not a noteworthy challenge.
Mechanical processing of the niobium parts is described in the following.

Cutting properties

Turning and milling of niobium is not comparable with machining of well-known metal alloys such as iron, aluminium or copper. The cutting properties of niobium are best comparable to those of pure aluminium; however, the toughness is much higher. Several cutting tests were carried out to ensure an efficient and smooth processing so that an optimal surface quality can be achieved.
It turned out that the cutting geometry is very important. Due to the bad cutting properties of niobium a particularly keen blade edge hast to be used. It is recommended to choose a high cutting angle and thus a small point angle. Tests with a cutting angle of up to 55° were carried out. This cutting geometry can only be reached by using HSS cutting inserts. As HSS tends to abrade quickly the accuracy of the contour could only be guaranteed for a short period of use. In addition these cutting inserts are very expensive and continuous application of this technique was stopped. Thereupon the usability of standard hard metal cutting inserts (HM) was investigated. When using HM inserts attention has to be paid to avoid to usage of chip breakers. The coating should be as thin as possible because each layer blunts the cutting edge and therefore complicates removal of material. In the end it turns out that a normal HM-insert for aluminium also fits best for removal of niobium. This insert does not offer best cutting conditions and also abrades moderately but the cost-benefit ratio is best. Furthermore it was defined that only unused inserts may be used.
The cutting data that were finally applied are shown in table 1.

Cutting insert	DCGX 07
Cutting speed Vc	250 – 300 m/min
Feed motion f	0,03 – 0,05 mm/U
Cutting depth a_p	Max. 0,2 – 0,3 mm
Cooling lubricant	1. FMS cool 250 ca. 6 % 2. Oemeta Unimet AS220 R ca. 15 %

Table 1: Cutting data for niobium processing

During processing niobium tends to shape a burr that is difficult to remove. Therefore it makes sense to account for the de-burring when programming the contour.

Turning device

Clamping of the half-cells for turning processing is another challenge due to easy deformability. The half-cell cannot be clamped in a three jaw chuck because of its shape. A fixture was developed which allows adjustment and clamping of the half-cell. The half-cell being clamped in the fixture can be put into the turning machine and can be flipped over for turning the other side without re-assembling. In this way iris and equator region can be machined without taking the half-cell out of the fixture. An optimal adjustment of iris to equator is hereby achieved (Fig.: 5 + 6).

Figure 5: Turning fixture for end half-cells

Figure 6: Assembled turning fixture

After machining attention has to be paid to the finished contour and that it does not have any contact to any other material. Deposition on the welding edge has to be avoided by any means because there is a risk that foreign materials might penetrate the niobium. It turned out that simple synthetic rings can be used as appropriate deposition.
Fabrication of a good circularity is significantly more difficult if the half-cells are made from large grain niobium. The few grain boundaries stay under high tension during deep-drawing. Even after calibration a shape deviation remains. In contrast to fine grain niobium where elliptical shape deviations may develop erratic deviations occur at the grain boundaries. Therefore clamping into the turning device has to be done with great care. The half-cell is pressed into a circular form and the recess is turned. When taking the half-cell out of the fixture it moves back into its original form. It then becomes very difficult to stick together the half-cells with a turned recess. These irregularities in part made it impossible to mount the half-cells with turned recess.
In this case a butt joint without recess is preferred. It is essential to achieve a constant wall thickness because otherwise there is the risk that during welding an incomplete root penetration or, in the opposite case, a hole is generated.
In spite of these difficulties it was possible to fabricate and test several one-cell cavities made from fine grain niobium. [2, 3, 6].

Cooling lubricant

Due to the exponentially increasing affinity of niobium to oxygen and to other gases at increased temperatures heating of the work piece has to be avoided during machining. At increased temperatures among others unwanted niobium oxides develop which, on one hand, result in embrittlement and on the other hand in a degradation of superconducting properties. For this reason the maximal temperature was fixed to 80°C.
The lubrication effect of the cooling lubricant (CL) is an important factor due to the poor cutting properties of niobium. Statements of the past indicating that isopropanol or the like can be used as LC proved wrong.
Prior to the release of a CL niobium flat test pieces were fabricated and subsequently welded with CLs from the firms Ometa and FMS. A successful investigation of the RRR-value of the welded niobium followed [7]. Hence the influence of the CL onto the niobium was investigated and the CL

qualified. All following one-cell cavities were processed with this CL.
In order to guarantee that no foreign material can reach the niobium via cooling fluid or via the machine's cooling fluid circuit an autarkic CL-supply was established in which only unused CL in clean lines can reach the components. The CL which was let out will be led in a collection tank and will not be re-used in the supply.
After processing all components are degreased and cleaned in a laboratory cleaner or in an ultra sonic basin.

II.C.6. Shape Control

In important information in the context of sticking together the half-cells with recess is to what extent the circularity in the equator and iris region deviates from the required design form. A deviation in circularity of 0.2 mm to 0.4 mm is within tolerance. In most cases the form will slightly resemble an ellipse. With the help of graphic display of the „uncircularity" it is possible to fit the elliptical half-cells congruently. Thus the recess can be sticked together without any problems. Wall thickness is also investigated as a wall thickness deviation of 0,1 mm is already critical during EB-welding.
Shape control is even more important if sheets were made form large grain niobium because the shape deviation of the half-cell is significantly more serious in comparison to sheets made from fine grain niobium. The measured deviations of half-cells made form large grain niobium was up to 1.6 mm (Fig.: 7). If such half-cells shall be welded an appropriate fit can be found by a circularity measurement It is recommended to use two sheets which laid side by side already in the ingot. In this case the irregularities of both sheets are similar and sticking them together will become easier.

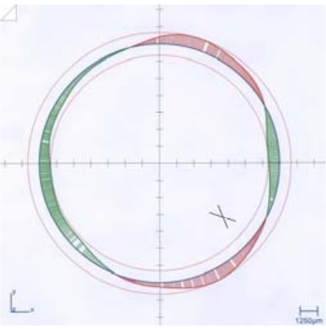


Figure 7: Example of a graphic display of large grain niobium's circularity

II.C.7. Electron Beam Welding

The requirement valid for all mechanical working steps that welding areas must not get in contact with foreign materials also applies to all preparatory welding handlings. All devices for etching, transport and stocking were constructed accordingly.

Electron beam welding plant [8]

At DESY an electron beam welding plant (EBWP) was put into operation in 2001 in Hamburg. The plant was dimensioned for the projected one-cell cavity test programme and the resulting ultra-high vacuum conditions (UHV) which are required at DESY.
Welding of the critical seams should be carried out at a total pressure of approx. 1.0×10^{-6} mbar. This vacuum pressure which is low for electron beam welding plants is reached with two refrigerator cryogenic pumps. They have a pumping capability of 10.000 l/s each.
The manipulators inside the welding chamber must work without lubricants in this vacuum level. For this reason a particularly tuned construction of the manipulators was necessary. Special attention was paid to the avoidance of virtual leaks such as blind holes drillings or big pending areas. At a few points, e.g. ball bearings, lubrication was indispensable. In these cases a special vacuum lubricant with low vapour pressure was used. With no exception high-alloyed chromium-nickel steel, aluminium and bronze were used. External or encapsulated operation of the engines is necessary. Prior to installation all components were degreased and baked out thoroughly.
All preparatory works for welding have to comply with high cleaning requirements according to UHV-regulations. Care has to be taken that the chain of UHV cleaning requirements is not interrupted starting from cleaning after machining of devices and the components to be welded.
Only strict compliance with theses requirements will maintain the status of a vacuum-technically clean and oil-free plant after many years of operation (see Fig. 8)

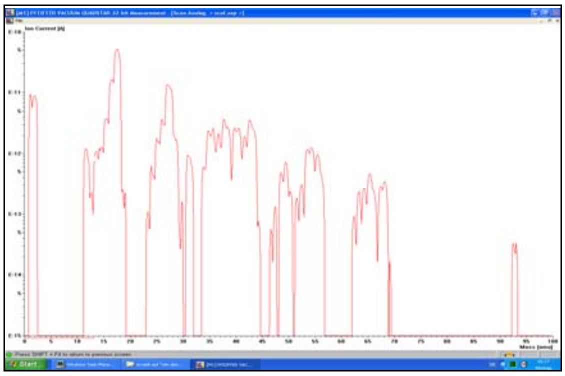


Figure 8: Residual gas analysis EBWP 2009

The residual gas analysis of the EBWP working chamber with a pressure of < 1.0×10^{-6} mbar does not show any masses > 44, that achieves 1/100 of the maximal partial pressure.

Chemical cleaning of the welding seam area

The welding edges are etched according to the procedure described in II.C.3. For this purpose the welding edges are dipped into acid ca. 20 mm for 5 min (removal rate ca. 5 µm). A magnetic stirrer constantly mixes the acid. After etching the respective component is washed in several steps in ultra-pure water until the discharge of the flushing water achieves a value of 16 MΩ.

Drying

After chemical treatment and flushing in ultra-pure water the components are wet. Prior to installation into the EBWP dryness of the components to be welded has to be secured. Therefore two procedures were established:
- Drying 1):
Blowing of the areas with filtered nitrogen
- Drying 2):
Drying in a vacuum cabinet dryer with the following parameters:

Temperature	60°C
Pressure	2 mbar
Duration	ca. 10 min.

Transport

The subsequent transport between chemistry lab and EBWP is carried out in an adequate container which can be evacuated. During transport the components are fixed in such a way that welding edges do not touch the clamping system and the inner surface of the half-cell is not damaged (Fig. 9).

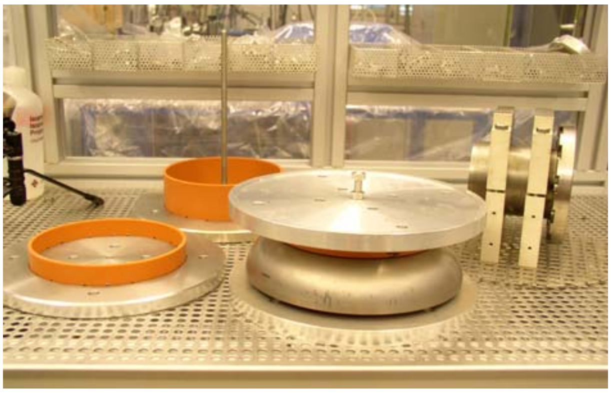


Figure 9: Half-cell and end tube with device

Storing „168 h rule“

According to the valid specification etched niobium parts had to be welded within 8 h and may not be exposed to oxygen for a longer period of time. If a period of ca. 8 h is exceeded niobium oxides are increasingly built. These oxides incorporate into the weldment and thus may have a negative effect on the thermal conduction (RRR) and consequently on the superconducting properties [9]. If 8 h are exceeded a second etching would be necessary. This dependency on time sequences requires a detailed planning of manufacturing resources. All preparatory works for welding have to be finished within one day-shift.
In order to reduce this time-dependency test-cavities were fabricated which after etching of the iris and equator area were stored in a vacuum-cabinet (2 mbar) respectively in a nitrogen cabinet for one week (168 h) and only then were welded. In this way it should become possible to etch a complete week's workload of components to be welded, take them out of the storing cabinet according to requirement and weld them.
The overall contamination at ambient air was minimized to 8 h as before.

Mounting and welding

Mounting of the welding joints takes place in a local clean room of class ISO 4 in order to minimize the risk that particles get in between the edges of components and become encased in the weldment during welding (Fig. 10) The electron beam welding plant itself is not located in a clean room but in a clean environment.

Figure 10: Local clean room with mounting area, vacuum transport container and N2 storing cabinet

In the following a welding sequence is described, taking an equator seam as example.

- Take the parts out of the transport container respectively out of the vacuum or nitrogen cabinet.
- Blow all components with ionized nitrogen.
- Install into tack weld fixture taking into account the circularity.
- Installation into the EBWP (without clean room).
- Blow all welding areas with ionized nitrogen.
- Close the welding chamber.
- Evacuate to 1.0 x 10^{-6} mbar.
- Adjust the joint.
- Eight tack welds (Length: 20mm) evenly distributed on the circumference
- Cool down, vent and open.
- Remove from EBWP and store in clean room.
- Disassemble tack weld system.
- Mount main welding system and beam dump
- Install into EBWP (without clean room).
- Blow the welding areas with ionized nitrogen.
- Close the welding chamber.
- Evacuate to 1.0 x 10^{-6} mbar.
- Adjust the joint.
- Pre-weld with 50% welding current, main weld with 100% welding current.
- Cool down, vent, and disassemble.

The fixtures for welding of beam tubes or of mounting rings are not particularly challenging and therefore are not described any further.

- **Iris**

In order to assure the specified surface quality and to minimize the risk of a hole at first the iris is welded from inside with an angle of 45° and a penetration of calculated 68 %.. Afterwards a re-assembly takes place and the iris is welded with an angle 0° from outside with a penetration of 56 %. The fixture is constructed in such a way (Fig. 11/12) that the beam tube is screwed to a ground plate and the half-cell is pressed on to the beam tube by means of four blank holders which are outside. The blank holders are equipped with niobium plates at the point where they grip the half-cells in order to prevent any possible contamination with foreign metals in the equator region.

Figure 11: Iris tack- and welding fixture for the inside welding position

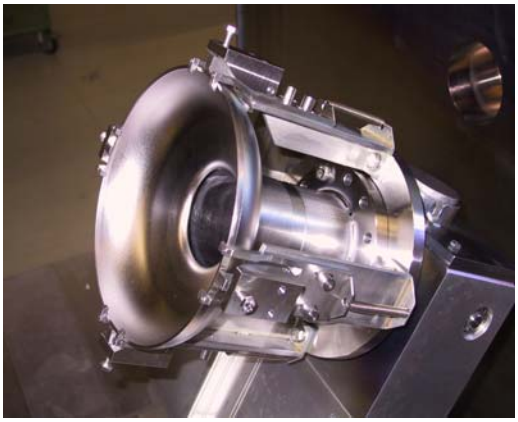


Figure 12: Welding fixture with installed half-cell and beam tube at 45°

For the outside welding position of the iris the fixture is removed and the „half cavity" is directly mounted onto the driver.

- **Equator**

For optimal mounting of the two half one-cell cavities a tack weld fixture (Fig. 13) was developed which allows compression of the recess with a defined force at eight points. Afterwards a thread rod with a beam dump is put through the cavity and thus attached to the driver of the cavity. On the loose side the weight of the cavity is depositing on two movable ball bearings.

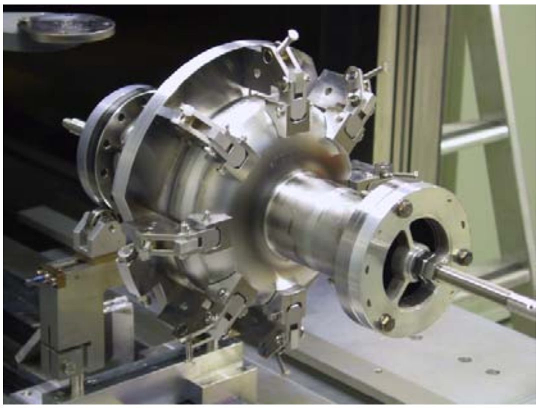
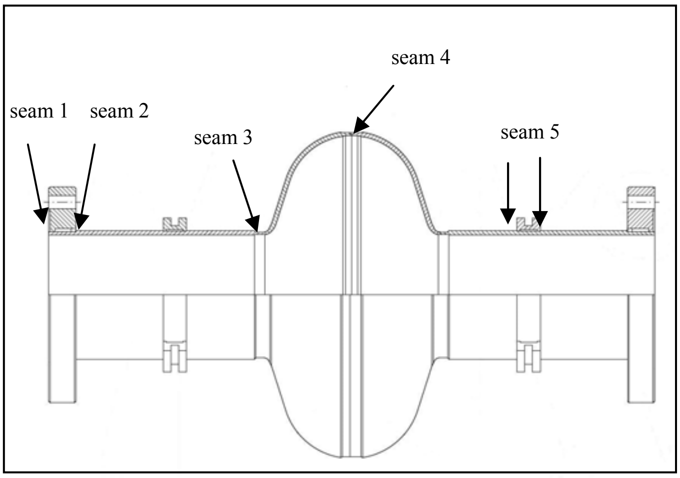


Figure 13: Tack weld fixture for equator

After tack welding the fixture is disassembled and the proper seam is welded. The equator is welded from outside, at first with a beam current of 50 %, then of 100 %. A welding sequence: first from inside, secondly from outside, of the equator is not possible due to the missing accessibility of the welding joint.

Welding sequence



Seam 1. 2x flanges on tube. vacuum side
Seam 2. 2x flange on tube, supporting seam
Seam 3. 2x beam tube at half-cell (Iris)
Seam 4. 1x „half cavity“ to „half cavity“ (equator)
Seam 5. 4x mounting rings, on both sides

Welding parameter

	Seam 1		**Seam 2**		**Seam 3**				**Seam 4**		**Seam 5**
Additional remark			In segments		From inside		From outside		From outside		
Maximal duration in ambient air after etching (h)	200		200		8		8		8		200
Welding procedure*	F	V	F	K	-	68%	-	56%	50%	100%	100%
Angle (°)	45	45	45	45	-	45	-	0	0	0	37
Accelerating voltage (kV)	150	150	150	150	-	150	-	150	150	150	150
Beam current (mA)	4	5	4	8	-	8	-	7	7	13	10
- Beam form	-	-	-	circle	-	circle	-	circle	circle	circle	circle
- Frequency (Hz)	-	-	-	4000	-	4000	-	4000	4000	4000	4000
- Amplitude (mm)	-	-	-	1,5	-	1,5	-	1,5	1,5	1,5	1
Focus position set (Δ Focus. opt.)	-15	-40	-15	-40	-	-25	-	-25	-45	-45	-35
Welding speed. (mm/sec)	8	5	8	6	-	6	-	6	6	6	7
Beam deflection DC (mm)	-	-	-	1,5	-	0	-	0,25	-	-	0,3
Slope in (angle)	45	45	5	5	-	5	-	10	5	5	3
Overlap (angle)	10	10	-	-	-	5	-	5	5	5	-
Slope out (angle)	40	40	3	3	-	25	-	30	25	25	2
Pressure of welding generator (mBar)	$< 1x10^{-7}$										
Pressure of working chamber (mBar)	$< 5x10^{-5}$				$< 1x10^{-6}$				$< 1x10^{-6}$		$< 5x10^{-5}$
Time of cool down (min)	10	10	10	10	-	120	-	120	-	120	10

* F: Fixing seam, V: Vacuum seam, K: Cosmetic seam, n%: % of theoretically required current for full penetration welding

II.C.8. Quality Control

After completion a standardized fabrication quality control takes place. All relevant mechanical measurements as well as the frequency are taken and saved. As at some intermediate steps, e.g. prior to equator welding, measurements of length were carried out and an averaged welding shrinkage could be determined. This is necessary for a good prediction of the cavity length needed for the compliance with the definite frequency. The welding seams are inspected with an endoscope and irregularities are saved as photo (Fig. 14).
If irregularities are localized during radio-frequency (RF)-cold-test („T-Mapping“) [10] results can be checked for correlation.

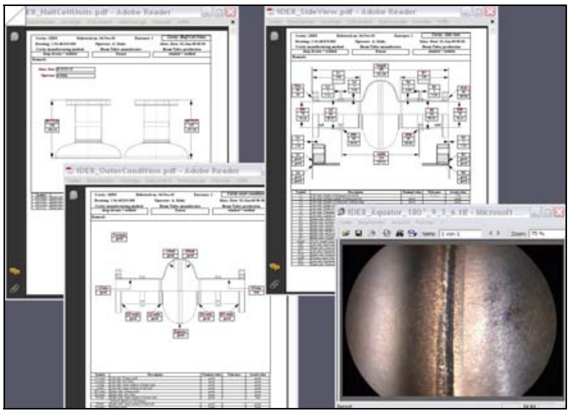


Figure 14: Example of reception inspection (1DE8)

II.C.9. Documentation

Process documentation is done with job tickets (Fig. 15) that summarize the most important working steps. The tickets have to be filled out after completion of respective working step and be passed on to the next one. All components are marked with a number and thus secure complete traceability. In this documentation protocols of all in-process-inspections such as shape control are summarized and filed in the DESY database.

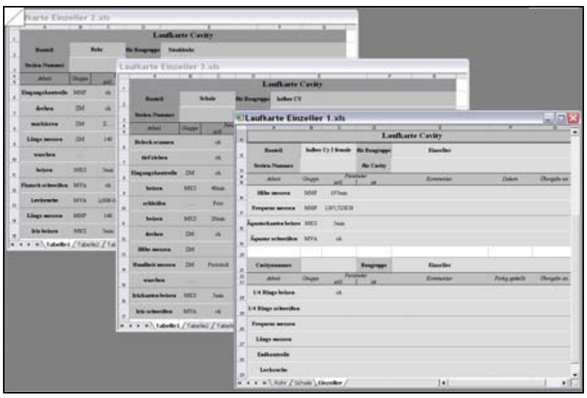


Figure 15: Move tickets

III. Surface Treatment

After mechanical completion and quality control the cavities must be submitted to a surface treatment before the first radio-frequency cold-test. As a general rule initially ca. 80µm of the inner surface are removed by chemical etching („BCP“). This is done either at DESY or at Research Instruments GmbH (formerly ACCEL Instruments GmbH). In the following the cavities are annealed at 800 ˚C for 2 h for hydrogen degassing and mechanical stress relief. The final removal of ca. 100 µm is done by electro-polishing (EP) at Henkel Lohnpoliertechnik GmbH. The industrialization of electro-polishing was part of the series treatment preparation of nine-cell cavities and proceeded smoothly. Final treatments are done in a clean room of ISO class 5 or better. The cavities are cleaned several times with ultra-pure water at a pressure of 100 bar (HD-rinsing), ultra-high vacuum-tight mounted, evacuated and leak checked. Subsequently they leave the clean room and are ready for the RF-cold test.
In order to achieve the maximal accelerating gradient at high Q-values of cavities fabricated and treated according to state of the art, a low temperature heating under vacuum or under protective gas at 120˚C - 130˚C is necessary [11, 12]. This may be done prior to or after a first RF-cold test.
Depending on the test series purpose or on the measurement result prior to further RF-cold tests more surface treatments were applied:

i) Only HD-ultra-pure water rinsing,
ii) Cleaning with CO_2 snow [13],
iii) BCP removal of ca. 10 µm + HD-ultra-pure water rinsing,
iv) EP removal of > 10 µm + HD-ultra-pure water rinsing.

IV. Test Results

The results achieved in the frame of the one-cell-cavity test programme can be found in [2, 3, 13]. Here only two series of measurement are described exemplarily.

IV.A. Qualification of Fabrication

In order to qualify the fabrication sequences the first three cavities were made from established niobium (Heraeus RRR300) (1DE1, 1DE2 and 1DE3). The cavities were submitted to the proven final treatment and were tested. During the vertical RF-cold test each cavity reached an accelerating gradient of more than 30 MV/m (Fig. 16). Thus fabrication was qualified.

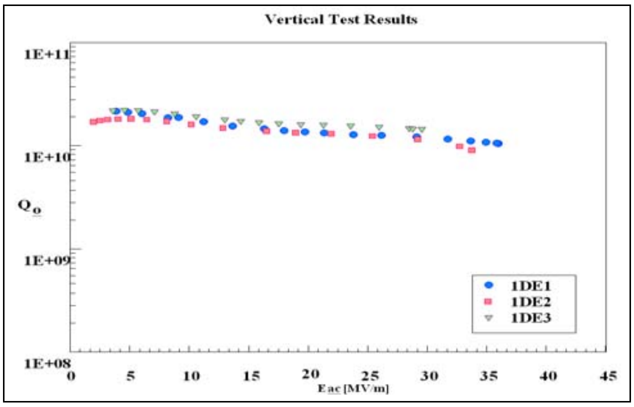


Figure 16: Result of cold test

IV.B. „168h Rule“ Cavities

Five cavities were made from established niobium (Heraeus RRR300) and final treatment was carried out with the proven preparation. The first cavity (1DE7) was the reference cavity and was fabricated according to the specification valid until then. This means that between etching and welding less than 8 hours passed.
The half-cells of the cavities 1DE8 and 1DE9 were stored in a vacuum cabinet for 168 h at 2 mbar after etching. The half-cells of 1DE10 and 1DE11 were stored in a nitrogen cabinet.
At first go all cavities showed a field strength and performance comparable to the reference cavity. (Fig. 17). The „68 hours-rule“ therefore is qualified. The option to store components after etching and weld them „just in time“ permits a significantly more flexible work scheduling.

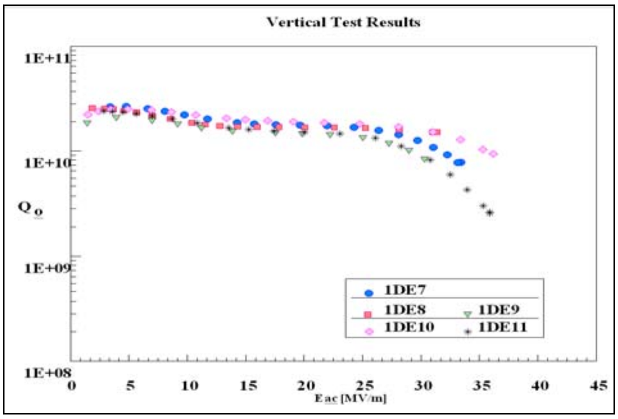


Figure 17: Result of cold test

V. Summary

Until now 25 DESY standard one-cell cavities were successfully fabricated and tested. All one-cell cavities reached field strengths of more than 30 MV/m to 42 MV/m at high Q-value.
Fabrication is possible without any problems and more cavities can be fabricated anytime reproducibly. In the course of the programme many details in regard to machining work sequence, to transport, to etching and to welding were improved which made possible a smoother and faster fabrication of the one-cell cavities.
In particular the 168 h-rule could be qualified which allows storing of the components after etching and “Just in Time”-welding. In regard to series fabrication for the European XFEL a significantly increased flexibility of work scheduling is rendered possible.
With the acquired knowledge additional prototype cavities can be fabricated. For instance a 0.6-cell and a 1.6-cell special cavity as so-called „Gun-cavity“ [14] were fabricated and successfully tested.

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