IMPROVEMENTS ON STANDARD FABRICATION METHODS

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ABSTRACT:

During the last decade a reasonable number of superconducting cavities made from solid niobium was fabricated by industry. They are made by standard fabrication technique like deep drawing, electron beam welding and trimming of shape by facing.

For the TESLA Test Facility [1](TTF) built at DESY Hamburg superconducting cavities of 1.3 GHz resonance frequency and average acceleration gradient of 15 MV/m have to be built by industrial companies. To study the state of the art of industrial fabrication techniques and the possibility of reaching reproducible acceleration gradients of 25 MV/m for a TESLA [2] application by these methods, the first 18 s.c. cavities were ordered and tested.

Most of the improvements reported on to gain high gradients, have been measured on single cell resonators under laboratory conditions. For accelerator application like TTF this technologies and treatment found under laboratory conditions, have to be transferred to industrial technology. During the test of TTF resonators, field limitations like quenches in cells or on welds as well as fieldemission were found. We report on the test results and the correlation between fabrication technique and field limitation. Basing on this experience improvements on fabrication technique were made. We report on the test results and improvements on standard fabrication methods made in 1997.

Results obtained during industrial productions

For the first two TTF modules a total of 24 resonators are fabricated by industry. 20 cavities were tested vertically at 1.8 K. A brought spread of acceleration voltages ranging from some MV/m up to 28 MV/m (see figure 1) was found while the quality factors were nearly identical in the 1-4 10^{10} range. Investigations made by rotating and fixed T mapping as well as mode analysis of the cavities are made to locate and analyze the origin of limitation [3].

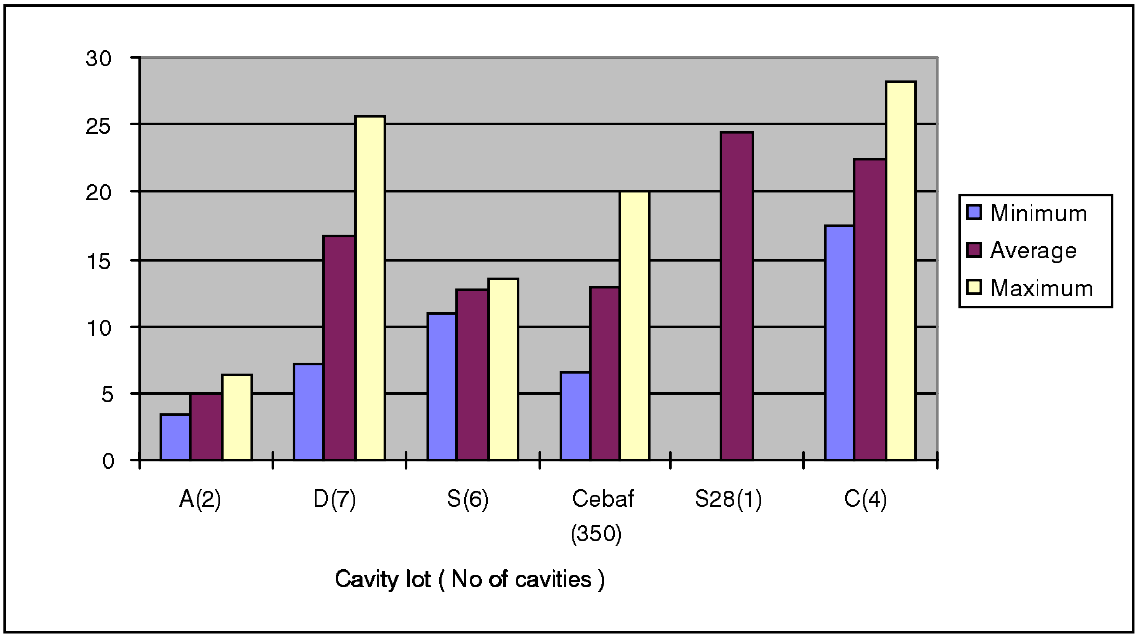

Figure 1 : Spread of acceleration voltages found for the fabrication of TTF cavities

Three major limitations on cavities were found during the test. Group one is limited by quenches in the niobium or the welding region, group two is limited by fieldemission and group three of the cavities is limited by RF power due to low Q values or acceleration field above 28 MV/m.The S cavity batch was always limited on the welds with an average voltage of 12,6 MV/m, even after postpurification at 1400 C. These cavities were made under the same fabrication conditions and sequences as used for the 350 resonators of CEBAF. The average voltage measured for this 350 cavities is 13 MV/m, well above the design value of 5 to 10 MV/m [4]. Improvements on preparation technique and welding parameters were applied in the S cavity production. A test resonator S28, where no heattreatment was applied, performed above 25 MV/m and is limited by the Rf power available in the teststand.

The C cavity lot reaches an average voltage of 22.3 MV/m. Two of the C cavities are heat treatment at 1400 C. After this treatment one cavity is limited by quench in one cell while the second is limited by fieldemission at 28 MV/m. Before postpurification this two cavities were limited at 20 MV/ by quenches on the welds.

All Cavities of the D lot were postpurified at 1400 C.nearly half of the D cavities reached well above 20 MV/m after this procedure one cavity is limited by RF power at 29 MV/m while the other 50 % are limited by quenches at low fields. These cavities show similar behavior in the RF test and could not be cured by addition chemical treatments of more than 100 μm removal [5]. One of these cavities was cut and an inclusion of Tantalum in the Nb bulk wall was found to be the origin of the quench [6].

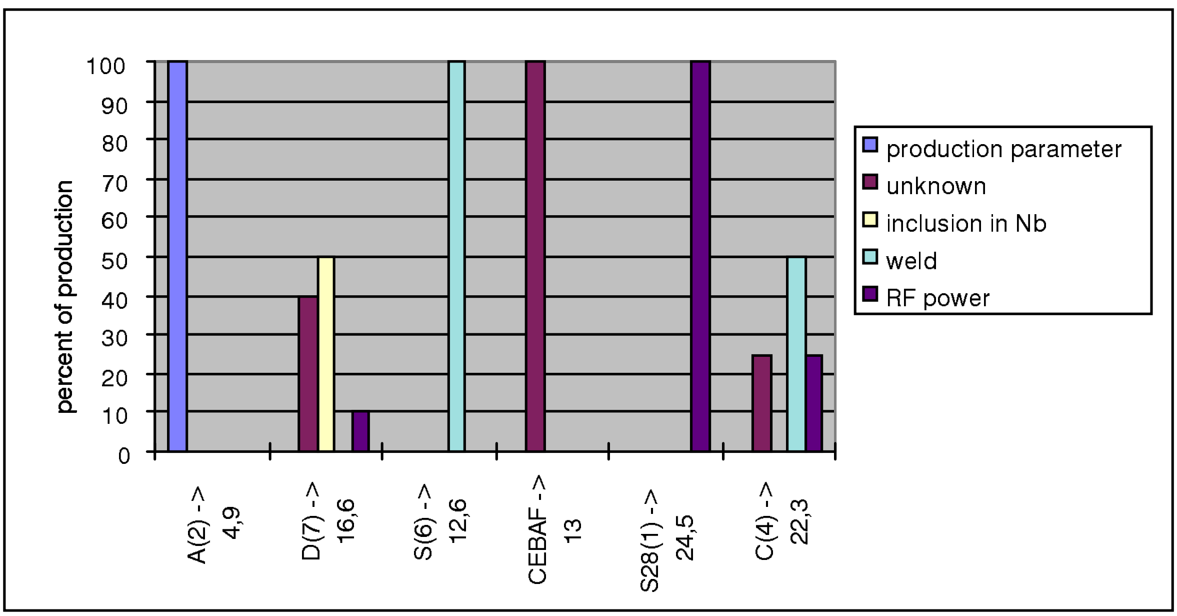

Figure 2 Limitation found on the s.c. cavities for TTF.

X-Y axis: name of cavity lot (number of cavities) -> average acceleration field (MV/m)

The two cavities of the A fabrication sequence showed typical mismatch of production parameters (Eacc = 4.9 MV/m). They were fabricated by a new vendor in the RF superconductivity field and show the typical learning curve. The non optimized production line resulted in a cavity where all welds performed badly. The second cavity produced so far is limited at 6 MV/m at a weld where a repair of the weld had to be done. All other welds perform around 17 MV/m, although there was no 1400 C treatment done so far.

Fabrication sequences:

The fabrication of a s.c. resonator consist of three major activities (see table 1). Each step of this production is of specific risks, which were investigated during the production and test of the first TTF cavities. The improvement of technique like eddy current scan of Niobium, improved welding technique and clean production will be applied for the 1998 production of 26 new structures.

Niobium	Cavity parts	Welding
Electron Beam Melting of Ingot in UHV oven	forming by deepdrawing	electron beam welding machine / set up and vacuum
Rolling of sheets from Ingot	facing on turning machine	electron beam welding parameter set
Cutting of circular or rectangular plates	preparation by chemical etching	preparation and sequence of welding

Table 1 General fabrication steps of standard fabrication technique for s.c. Cavities

Fabrication of Niobium

For the fabrication of a s.c. resonator the quality of the niobium is a fundamental factor for high gradients. The amount of Niobium with a residual resistance ration (RRR) of 300 or better and in addition no clusters of impurities is only a small percentage of the world wide production of Niobium. The production of this high qualified Niobium is made in the standard production line in industry. The UHV electron beam (EB) melting ovens are in use to produce tantalum or other high melting elements [7]. It can not be

Process	melting	rolling	Cutting
risc	impurities not evapurated and melting point above 2300 C	contamination and lamination (standard fabrication envoirements)	scratches and contaminations (standard fabrication area)
Quality control	RRR of Ingot and samples (but local clusters are statistic)	visual inspection of the surface (only surface colorations and non regularities are visual)	visual inspection of the surface (only surface colorations and non regularities are visual)

Improvemen in 1997	Scanning of Niobium sheet material by eddy current aparatus => material clusters (Tantalum) / surface defects / holes and laminations down to 0.3 mm depth were located

Table 2 Fabrication and quality control for Niobium production

guarantied that particles, remaining from the former melting processes, fall into the molten Niobium. These and other non evaporating clusters are of statistical nature and cannot be removed from the Niobium by Titanium postpurification. For forming of cups and tubes the one ton heavy ingot is rolled down to sheet material. The rolling process should be done under clean conditions to avoid contamination of the Niobium. The rolling mill and the fabrication area, however, are standard environments. Particles falling down on the niobium are pressed in to the bulk. Only contamination of niobium and scratches located on the surface can be located during optical inspection. For the deep drawing process the Niobium band is cut into rectangular or circular discs. Here cutting by a stamping machine, machining on a turners lathe, water cutting or erosion cutting is applied.

Hydrogen contamination was measured in the cutting area of water and erosion cut sheets [8].

Contamination resulting from the production of the Niobium sheet material can not be cured during the preparation of the cavities. An eddy current scanning apparatus was developed and successfully installed in the quality control of the Niobium fabrication. Contamination like Tantalum and Iron as well as laminations can be detected during the scan of the Niobium to be used for the next cavity production. 5% of the sheets scanned so far were rejected. The statistics in good agreement with the statistics of Niobium defects found on the cavity tests.

Fabrication of Cavity parts

During fabrication of cups, cells, beampipes and stiffening rings standard fabrication technique is applied. The cups are made by deep drawing. The height of the cups is machined by trimming on a lathe machine. Significant variations in geometry, related to the forming technique in use and the precession of lining, were found. Both fabrication steps shift the resonance frequency f_o and mechanical length of the cavities ($df/dl|_{9cell}$ = 300 KHz/mm). The mechanical tolerances of the tool for deep-drawing and lining are of systematic nature and can be corrected in the fabrication process. The variation in thickness of the Niobium influence the geometry statistically. Deep-drawing on moles made from a rubber Silicon sandwich showed the best reproducibility and relaxed dependency on the Niobium parameters so far.

EB welding:

A significant percentage of field limitation (Eacc) was found to be on the welds which are made by EB welding in ultra high vacuum. To study of the influence of vacuum in the EB welding chamber on the RRR of the Niobium,

several test samples were made on machines in use for TTF cavities. Below a total pressure of $5E^{-5}$ mbar no significant reduction of RRR in the weld region was measured [9]. The geometry of the weld which is influenced by the EB welding parameters seems to be correlated to the maximum acceleration

	weld geometry			welding sensitive for		
Electron beam	weld seam	under bead	Rf surface	current / velocity	farication tolerances	reprodu-cability
Focused	very small	strong	rough / jagged	very sensitive	extreme sensitive	low
Defocused	small-> brought	strong	rough -> smooth	sensitive	sensitive	low -> good
Rhombic raster	brought	low	smooth	relaxed	small	good
Wiggled	brought	low	smooth	relaxed	small	good
1st wiggled, 50 % penetration 2nd wiggled full penetration	brought	plane	shine	relaxed	very small	very good

table 3 Influence of beam parameters on welding bead geometry

voltage. Cavities with high gradients show smooth and shine welding seams with a plane underbead (C and D cavity lot) while rough and jagged welds limit at very low electrical field (A cavity lot). Table 3 compares different parameters which are in use for NB welding and the quality resulting from the parameters chosen.

Treatment and sequences.

treatment	Eacc of fabrication lot	limitation (detected by T mapping)	improvement by Ti postpurification at 1400 C
degreasing with alcohol	Eacc = 12 MV/m	global heating of weld region	NO Eacc = 12 MV/m
welding etch cleaned by BCP * etching and clean water rinsing	Eacc 15-25 MV/m	local spots on weld region	YES Eacc up to 26 MV/m
welding etch cleaned by BCP * etching, ultra clean water rinsing and clean environment	Eacc 20-22 MV/m	local spots on weld region	YES Eacc >28 MV/m Test limited by e- rf power

Table 4) Correlation of preparation techniques for EB welding seams and cavity performance

BCP* buffered chemical polishing $HF/HNO_3/H_3PO_4$ composed by volume 1/1/2

The average voltage (Eacc) of the S cavities for TTF the welds is in good agreement with the results of the CEBAF production. The quench limitation on the weld can be assigned to the insufficient cleaning sequence applied for EB welding. The statistic gained so far shows a correlation of field limitation on welds and preparation procedure in use for EB. welding (table 4).

Result of improved fabrication in 1997

According to the experiences gained so far general fabrication steps are necessary to reach acceleration voltages in the 20-30 MV/m regime.

1) Scanning of Niobium as quality control to avoid basic defects in the bulk of the resonator. With this method the quench limitations, which were for a long time the limitation towards high gradients, can be sorted out in a very early step of the production.

2) A control of the chemical etching by temperature control of the bath to < 15 C and the quality of the rinsing water after the chemical etching. This needs to be applied to avoid Hydrogen contamination of the Niobium and drying stains that will be welded in or result in chemical reactions due to heating up during welding

3) Short storage of the etched welding seams before welding.

4) Use of a wiggled beam with a 50 % penetration on the first welding turn, followed by a wiggled full penetration beam. This sequence is less sensitive to fabrication tolerances like the defocused beam applied on the C cavities. which reached high gradients after heat treatment at 1400 C.

5) The vacuum in the EB welding chamber should be lower than $5*10^{-5}$ mbar, measured close to the cavity. The improvement on RRR of the Niobium can only be preserved if the oxygen partial pressure at the weld is low.

6) Cleanliness after chemical etching and during the assembly. All residues of the environmental and the dust falling down on the welding etch will evaporate (risk of burning holes) or will be welded in.

This sequence was applied on the cavity S28 which performed at 25 MV/m without postpurification and is limited by the available rf power on the test stand. The welding regions is not limited by quench up to 27 MV/m. For the C most of this sequences could be applied. These cavities showed limitations on the welds around 20 MV/m, which could be cured by a heat treatment at 1400 C. After this treatment the acceleration gradient of 28 MV/m was limited by fieldemission

Conclusion

Basic fabrication errors like inclusion in the Niobium as well as wrong sets of welding parameters or fabrication sequences result in low performances of s.c. resonators. The production of cavities in companies used to machine Niobium and the application of high RRR Niobium as well as basic rules of cleanliness and welding technique results in cavities that perform in a region of 10 to 15 MV/m. Higher acceleration voltage could be made by improvement of cleanliness in fabrication, improvement on EB welding technique and the application of scanned high RRR Niobium. The multicell cavities made under this conditions perform in the 20 to 30 MV/m regime. Even here limitations on the welds were found that limited some cavities at 20 MV/m without heat treatment at 1400 C.

It has to be studied in detail if which improvements on the fabrication will give a further upgrade of the acceleration gradients. According to the results obtained up to now, it seems that quenches above 30 MV/m in multicell structures can be avoided by consequent application of cleanroom technique in the fabrication followed by postpurification of the Niobium. The information coming from optical inspection of the resonators show that the fieldemission limitations found so far are not due to surface irregularities. Most results could be related to particles origin from the assembly procedures and tooling used for final preparation prior the rf test. The preparation for test has to be studied in parallel to the improvement of fabrication technique to reach cavities with acceleration gradients above 30 MV/m.

Acknowledgments

I like to thank the companies, involved in the production, and the colleges of the TESLA collaboration for supplying information and for open discussions with great acknowledgment.

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