INDUSTRIAL PRODUCTION OF 8 SUPERCONDUCTING ACCELERATOR MODULES FOR HERA AND 6 SUPERCONDUCTING ACCELERATING CAVITIES FOR DALINAC

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Abstract: In a first step of energy upgrading with superconducting cavities 8 accelerating modules, each consisting of one cryostat housing two superconducting (s.c.) cavities (4 cells, 500 MHz), will be installed in HERA [1]. After constructing three prototype cavities, Dornier is now building cavities and cryostats. Cavities delivered up to now showed Q values of 1.6 to $2 \cdot 10^9$ and accelerating gradients of up to 8.5 MV/m in low power tests. Critical parts for heat transfer of the cryostat have been calculated and optimized to 80 W. The first test run resulted in measured losses of 70 W. Cavities (20 cells, 3 GHz) constructed for DALINAC reached accelerating gradients of up to 6.5 MV/m under beam conditions.

Cavities for HERA

Design

As described in various publications [2], [3] the layout of the cavities (Fig. 1) with beam tubes, HOM couplers, and the input coupler port was designed by DESY, Dornier was responsible for the helium tank welded to the cavity with displacement bodies, reducing the amount of LHe to less than 100 l per cavity.

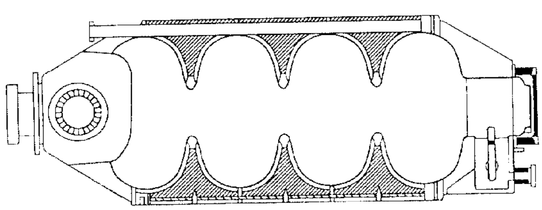

Fig. 1: Layout of the 4-cell 500 MHz cavities for HERA

Construction and treatments

Construction and surface treatments followed strongly the fabrication steps experienced during constructing the prototype cavities. Different with respect to those was the niobium used with an RRR of about 300, instead of a material with an RRR of 100 both delivered by W.C. Heraeus [4] and the replacing of the HIP bonding by a brazing technique to join the stainless steel flanges to the beam tubes, the coupler ports, and the HOM outputs. In the following the production steps are listed and briefly commented.

Forming of parts: half cells and tapers are formed by spinning, as far as tubes are not commercially available they are rolled and eb welded.

Tuning: After machining to a certain length, the half cells are paired to cells and the frequencies are measured. The cells are tuned by remachining the iris and equator regions before welding.

Welding: all niobium parts are connected by eb welding.

Brazing: during the prototype production bondings between the niobium parts and the stainless steel flanges had been performed by hot isostatic pressing (HIP), even if experiments on samples resulted in excellent joinings, this technique showed a reproducibility which was not sufficient for series production. Therefore a brazing technique was developed using an intermediate Cu ring. With this methode, the reproducibility is nearly 100% for flanges of CF 35 size, and about 80% for larger flanges, respectively.

Mechanical surface treatments: if ever the surface of the half cells showed irregularities, these were removed by mechanical polishing. To avoid misfunction by projections eventually produced during welding, all cavities have been tumbled.

Surface chemistry: the niobium parts have been treated chemically several times:
1) before inspection the original niobium sheets have been immersed into water with HCl as an additive to identify inclusions, especially Fe;
2) after spinning and machining the half cells were anodized to visualize defects;
3) a chemical polishing of the half cells by immersing the parts into a medium buffered acid removed 40 µm of the uppermost damage layer;
4) a chemical polishing, performed with partly filling the cavity with strongly buffered acid and turning it around its middle iris, removes further 40 µm from the completed cavity. Finally the cavity is rinsed with ultrapure 18 MΩcm water. Fig. 2 shows 5 cavities waiting for this procedure.

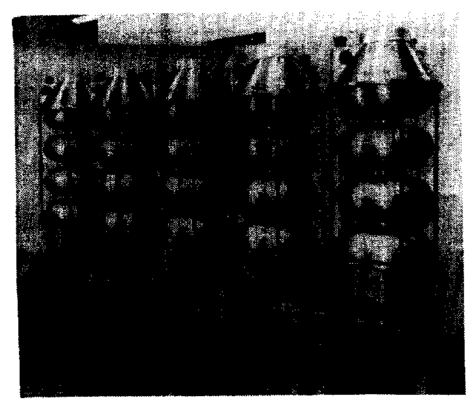

Fig. 2: HERA cavities before final chemical treatment

Results

In the end of April 1990 14 cavities have been mechanically completed, 8 cavities are ready for measurements and have been delivered to DESY, 5 cavities have been measured. The rf measurements performed by DESY with low power input couplers show accelerating gradients between 5.5 and 8.5 MV/m, all exceeding the design value of 5 MV/m with Q values in the range of 1.6 to $2 \cdot 10^9$ [5]. The measured Q values are generally some what lower than the design values. This reduction may be explained by the BCS resistance which is increasing with the RRR of the material, as calculated by Martinez and Padamsee [6] and experimentally verified at CERN [7].

Cryostats for HERA

For the 16 4-cell cavities 8 cryostats have to be manufactured. For shielding the 4.2 K LHe tank against the outer wall of the cryostat at room temperature a copper shield is mounted and cooled by 40 to 80 K cold He gas. The heat losses of the prototype cryostats were between 150 W and 200 W which is much too high and had to be reduced to a value of about 80 W. The main sources for the heat losses are openings in the cryostat as beam tubes, rf coupling holes, and especially the three-point suspension to fix the two cavities in the middle of the cryostat. Reducing the losses could be done by:

1) reducing the cross-section of the 3-point suspension and using poor heat conducting material,
2) increasing the heat resistance of the adjusting screws for the 3-point suspension and the heat shields,
3) finding the optimum point at the suspension to connect the 40/80 K gas cooling,
4) optimizing the location of the heat exchanger at the beam tubes.

Heat losses of the copper shielding: The heat shieldings are isolated against the outer wall by vacuum and 20 layers of superisolation NRC-2 with glas fiber textile [8]. Great attention was given to the contact pressure acting against the layers during mounting the 20 layers. The adjusting screws were fabricated of Inconel 600 instead of Monel, which reduces the calculated losses from 3 W to 0.5 W per screw. The heat losses for the insulated copper shieldings were calculated to be 10 W.

Heat losses of the coupling holes: Using the tube dimensions the heat losses for the couplers were estimated to 20 W.

Heat losses at the beam pipes: To minimize the losses at the beam flanges, the heat exchangers were optimized at 50 K and at a distance of 280 mm from the beam tube end. The heat flux from 300 K to 50 K was calculated to 6.5 W per tube.

Heat losses at the 3-point suspension: Always two cavities are fixed in the middle of one cryostat by a three-point suspension. This means a heat transmission between 4.2 K and 300 K. To minimize the losses the 40 to 80 K He gas circuit had to be fixed to the calculated 55 K point of this thermal bridge. Furthermore the suspension is now constructed from a light metal alloy which has a much lower thermal conductivity than the material used before. Diameters have been optimized to reach highest stability and lowest heat transfer. The heat losses for the three components of the suspension were calculated to 40 W. Fig. 3 shows the 3-point suspension of the cryostat.

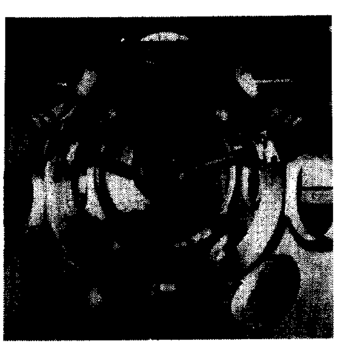

Fig. 3 Three-point suspension of the HERA cryostat

Results

The integral losses for the gas cooling circuit had been calculated to (80 ± 10) W for one cryostat. First experiments at DESY showed measured losses in the range of 70 W.

Accelerating cavities for DALINAC

For upgrading the electron accelerator at Darmstadt University [9] - DALINAC -, Dornier is constructing six accelerating cavities (20 cells, 3 GHz) (Fig. 4).

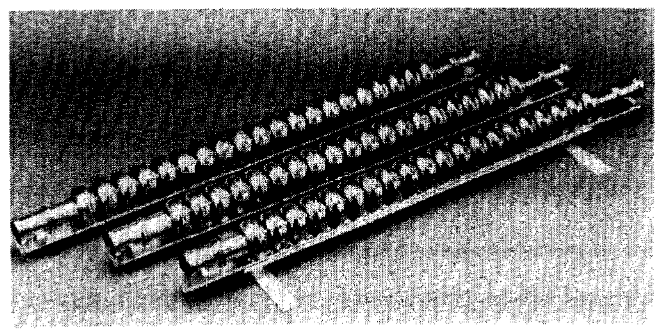

Fig. 4 Accelerating structures for DALINAC

The spherical design, developed by Wuppertal University [10] is slightly modified to an elliptically one. The calculations adapting the accurate geometry to the frequency have been performed by Darmstadt University. The advantages of the elliptical shape are a better rinsing and drying because there are no flat parts in the cells, and a higher stiffness as pointed out by [11]. The material used was niobium sheet material of 2 mm thickness with an RRR of about 300 for the cells and rod material with RRR of 100 for the cut off tubes both delivered by W.C. Heraeus [4]. Because installing of the field flatness is - including all model calculations - very time consumptive and therefore quite expensive, definition of the sequence of the cells of the cavities and tuning the completed cavities to a field flatness of less than 10% was performed by Darmstadt University.

Fabrication

The fabrication of the cavities includes following steps:

Forming: the cups were formed by deep drawing, the beam tubes have been machined from rod material.

Welding: all joinings between the niobium parts have been performed by eb welding; at first cells have been produced; the sequence of the iris weldings was performed in such a way that each iris welding could easily be inspected and if necessary mechanically be treated.

Mechanical treatments: if ever defects at the inner surface were observed, they have been removed by mechanical polishing: after water/HCl treatment, deep drawing and machining, welding of cells, and welding of the irises.

Chemical treatments: to detect intrusions, especially Fe in the original material, the sheets delivered wewe kept for several days in water with HCl as an additive. The solvent to etch the damage layer, to tune the single cells (see below), and to bring the completed cavities to the correct frequency a mixture of HF, HNO_3, and H_3PO_4 in the composition of 1:1:1 was used. Final rinsing which was done with ultrapure water of 18 MΩcm.

Tuning

Deviations in the μm range from the calculated geometry result in frequency deviations of the cells after deep drawing, n.c. machining and welding. Fig. 5 shows the frequencies of 110 middle cells. Frequencies

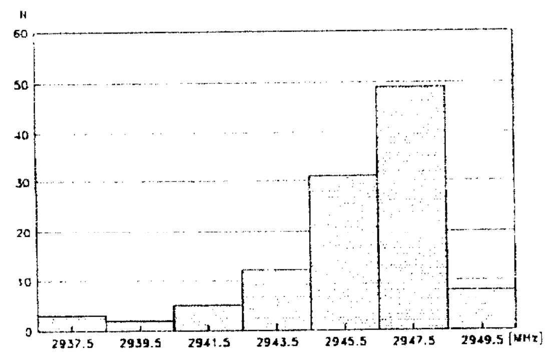

Fig. 5 Frequency distribution of 110 DALINAC cells

lower than the design frequency of (2942.2 ± .1) MHz can be increased by elongation of the cells. Frequencies higher than the design value can be tuned down by chemical etching of the inner surface. As described in [10] this tuning can be performed by immersing the cell in the etching bath or by local etching at the equator region. Both methods have been used.

After tuning the completed cavitiy to a field flatness to about 10% at Darmstadt University, the final surface treatment and the installation of the correct frequencies of (2991.25 ± .25) MHz at room temperature is done by immersing the cavity in the etching bath.

Results

At the end of april 90 the six cavities ordered from Darmstadt University have been mechanically constructed. Three of them have been finally chemically treated. The cavity measured up to now reached an accelerating gradient of 6.5 MV/m measured by the energy gain of the accelerated electrons [12].

Acknowledgements

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Literature

[1] G.-A. Voss, Proc. of the EPAC 88, Rome, page 7 - 10

[2] B. Dwersteg, W. Ebeling, W.-D. Möller, D. Proch, D. Renken, J. Sekutowicz, and D. Tong, ibid [1], page 1281 - 1283

[3] G. Arnolds-Mayer, A. Matheisen, W.-D. Möller, and D. Proch, ibid [1], page 938 - 940

[4] W.C. Heraeus GmbH, Heraeusstr. 12 - 14 D 6450 Hanau 1

[5] B. Dwersteg, A. Matheisen, W.-D. Möller, D. Proch, D. Renken, and J. Sekutowicz, this conferenc

[6] E. Martinez and H. Padamsee, REP. SR4 841201-EX Cornell University, 1984

[7] G. Arnolds-Mayer, C. Benvenuti, D, Bloess, G. Cavallari, E. Chiaveri, M. Hauer, N. Hilleret, M. Minestrini, V. Palmieri, L. Ponto, F. Scalambrin, and W. Weingarten, CERN/EF/RF86-1, 1986

[8] H. Burmeister, W. Eschricht, G. Horlitz, D. Sellmann and Ye Jia Ding, DESY HERA 87-24

[9] V. Aab, K. Alrutz-Ziemsen, R. Amend, D. Flasche, H.-D. Gräf, V. Huck, K.D. Hummel, M. Knirsch, F. Lindquist, W. Lotz, A. Richter, T. Rietdorf, U. Schaaf, S. Simrock, E. Spamer, A. Stiller, O. Titze, H. Weise, W. Ziegler, H. Heinrichs, H. Piel, J. Pouryamout, ibid. [1], page 335 - 338

[10] T. Grundey, Thesis Wuppertal University, WUB 85-15, 1985

[11] H.P. Vogel, DESY M-87-04

[12] H.-D. Graef, priv. comm.