New Achievements in RF Cavity Manufacturing

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Abstract

Dornier has been engaged in development, manufacturing and testing of Cu-, Cu/Nb- and Nb-cavities for many years. Recently, several different types of RF cavities were manufactured:

A prototype superconducting (s.c.) **B-Factory** accelerating cavity (1-cell, 500 MHz) was delivered to Cornell University, Lab. of Nuclear Studies.

A second lot of 6 s.c. cavities (20-cell, 3000 MHz) was fabricated on contract from Technical University of Darmstadt for the **S-DALINAC** facility.

Finally, the first copper RF structures (9-cell, 1300 MHz) for **TESLA** were finished and delivered to DESY, two s.c. niobium structures of the same design are in production.

Highlights from the manufacturing processes of these cavities are described and first performance results will be reported.

I. INTRODUCTION

Development, design and manufacture of RF accelerating structures has a tradition at Dornier for more than ten years. Single and multicell structures made from copper, superconducting (s.c.) niobium or from niobium sputtered on copper have been manufactured in a variety of configurations and sizes, from the 95mm ϕ 3 GHz structures up to the 350 MHz cells of the LEP size with 735 mm diameter. The production of 8 complete cryomodules - each housing two s.c. 4-cell 500 MHz cavities - for HERA at DESY was one of Dornier's outstanding achievements in the past years. These modules are now in full operation on the beam at HERA and contribute to the 30 GeV electron beam energy. Several publications exist on the manufacturing and the performance of these cavities [1], [2], [3].

II. NEW CAVITIES PRODUCED AT DORNIER

A. B-Factory cavity for Cornell University, Laboratory of Nuclear Studies

On contract from Cornell University, LNS, two prototype cavities were manufactured for the planned B-factory ; one RF model, made from 3 mm OFHC copper sheet metal, and one made from 3 mm niob material with an RRR of 200 (fig. 1). The design strictly followed the layout derived by Cornell which is described e.g. in [4]. Both cavities were complete with waveguide couplers which consist of a mechanically rather complicated, tongue-shaped coupling iris. A special feature of this cavity type is the so-called "fluted" beam tube which is to take care of the propagation of the TM_{110} and TE_{111} modes; both tubes (the Cu and the Nb one) were provided by Cornell and integrated into the cavity at Dornier. First measurement results of the copper model as well as of the niobium strucure are reported in [5] and [6].

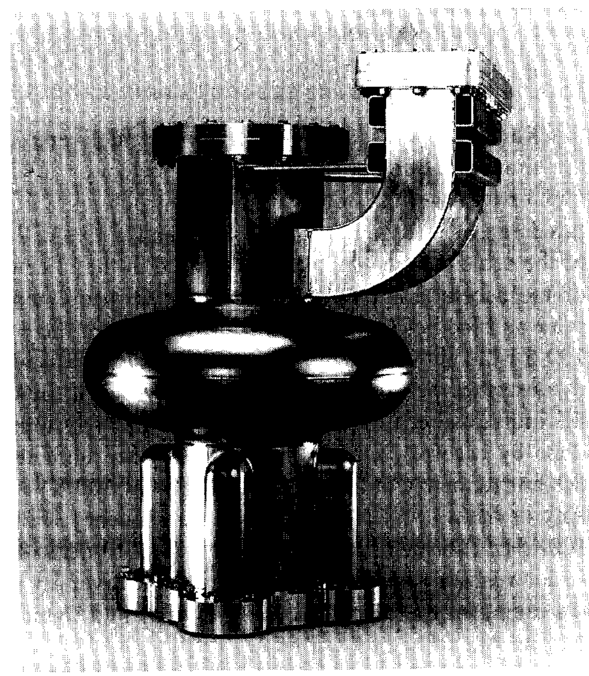

Figure 1. Superconducting Prototype B-factory cavity.

While the manufacture of the cavities followed standard procedures - the cells were made by spinning -, special care had to be taken for the chemical treatment of the Nb prototype in order to avoid the "Q-virus" [7], a degradation of the Q-factor due to a niobium-hydride phase change at the inner surface of a cavity. A buffered chemical polish (BCP) was used consisting of HF (48 %), HNO_3 (65 %) and H_3PO_4 (85 %) in a ratio 1:1:2; in total 100 μm were removed in several steps (30 + 30 + 30 + 10 μm); special caution was obeyed to control the temperature of the acid bath at 21 °C and, especially, to drain the used acid as fast as possible from the cavity vessel and to start rinsing with ultrapure water (conductivity < 0.055 μS/cm) immmediately after. First performance tests made at Cornell indicate that this process may have been a succesful remedy for curing the Q desease (s. fig. 2).

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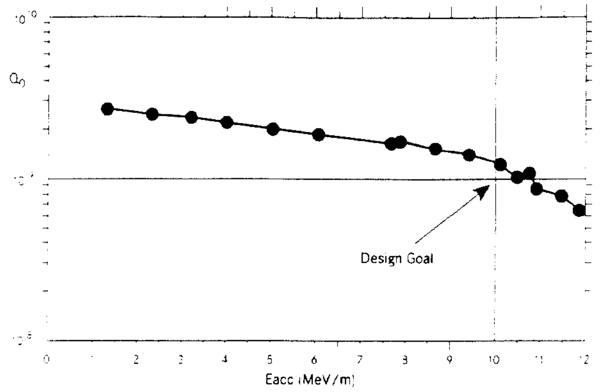

Figure 2. Q vs. E_{acc} for B-factory cavity at 4.2 K (courtesy of Cornell/LNS).

B. S-DALINAC Cavities

Further to the six s.c. 20-cell cavities delivered earlier for the the upgrading of the electron accelerator at Darmstadt University, another set of six 3 GHz structures was manufactured recently, together with a two- and a five-cell structure of the same design which are to be used in the injector section of the accelerator (fig. 3). The material was essentially the same as used before (2mm sheet, RRR 280 for the cells, RRR 100 for the cut off tubes), the manufacturing steps were already described before [1]. After deep drawing of the half cells, the individual cells were welded and chemically tuned; this is done by carefully etching the inner surface until the desired design frequency of 2991.0 $\pm$ .2 MHz (at 300 K) is reached. Any deviation of 1.5 μm results in a frequency shift of about 100 kHz. The tedious matching of the 120 cells for the six structures was performed by Darmstadt University as well as the tuning of the completed cavities to a field flatness of $\pm$ 1 % (fig. 4).

After the final chemistry, the cavities were baked out (750 C, UHV) at University of Wuppertal before they were installed in the accelerator. Thus, a maximum accelerating gradient of 10.1 MV/m and an average value of 5.6 MV/m was achieved.

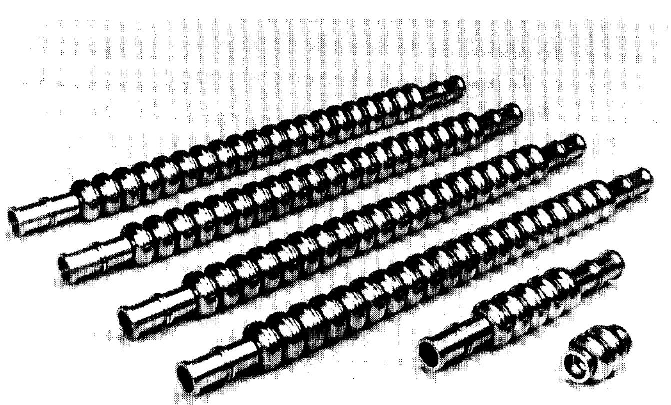

Figure 3. 3 GHz cavities for S-DALINAC.

C. TESLA cavities

The optimization of the shape of the cavities for the 1.3 GHz TESLA-Collider has been subject to intensive study [8]. It was analyzed [9] that the mechanical loads imposed during resonator fabrication and pressure tests and those loads exerted by the Lorentz forces during operation at gradients above 20 MV/m must not lead to inelastic cell deformation. Otherwise, the induced frequency shift due to wall deformation of the cavity cells would be considerably larger than the bandwidth of the resonator.

These requirerents implied that a sufficient wall thickness of at least 2.5 mm has to be kept also after deep drawing of the cells and that the calculated geometry of the cells must be met by $\pm$ 0.2 mm. Finally, the alignment tolerance of the iris diameters of the 9 cell structure has to be below $\pm$ 0.3 mm.

On contract from DESY, Hamburg, we manufactured five copper RF models of the 9 cell 1.3 GHz TESLA cavities (fig. 5). The half cells were formed by deep drawing from 2.5 mm OFHC copper sheet material. By special jigs and tools for shaping the half cells, by chemical preparation of the welding edges and by experimental verification of the welding shrinkage the required accuracy could be achieved for the cell shape (fig. 6) as well as for the iris alignment. The high level of reproducibility of the manufacturing process is underlined by the fact that a field unflatness of < $\pm$ 5 % was reached for all five cavities without tuning (fig. 7).

For testing purposes, the cut-off tubes were made removably, also three different diameters for the input couplers were machined into these tubes for testing. These parameters are being optimized by the involved laboratories.

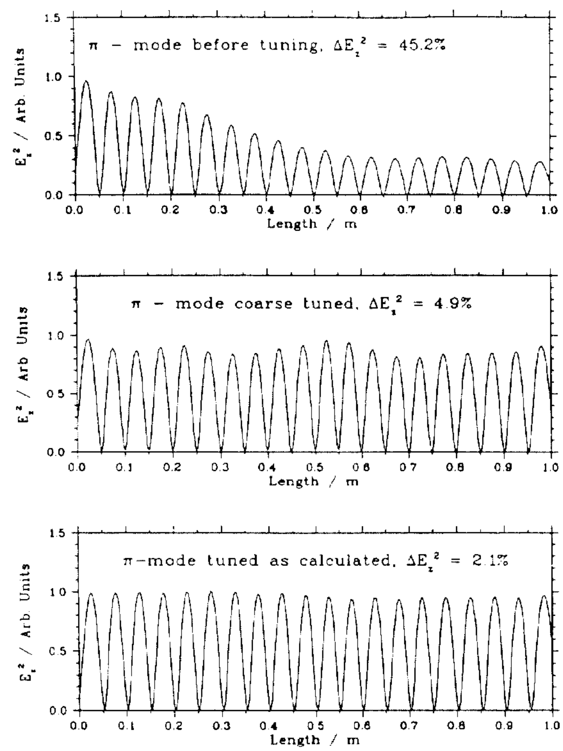

Figure 4. Field flatness of S-Dalinac cavities (courtesy of TH Darmstadt).

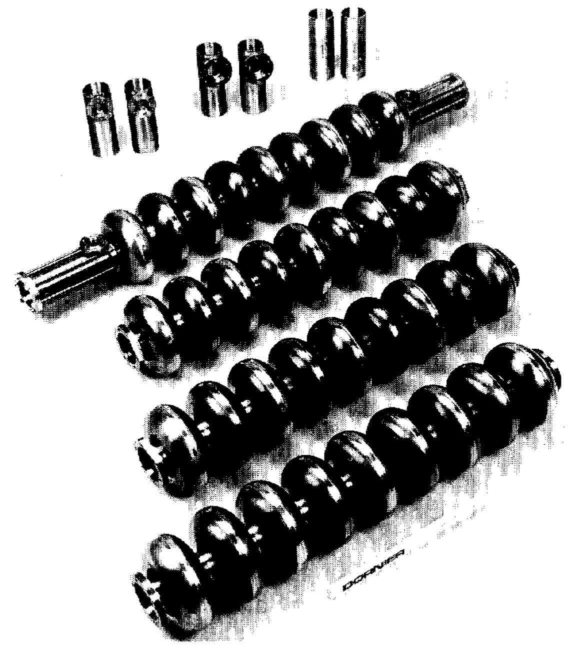

Figure 5. RF models of 1.3 GHz TESLA cavities.

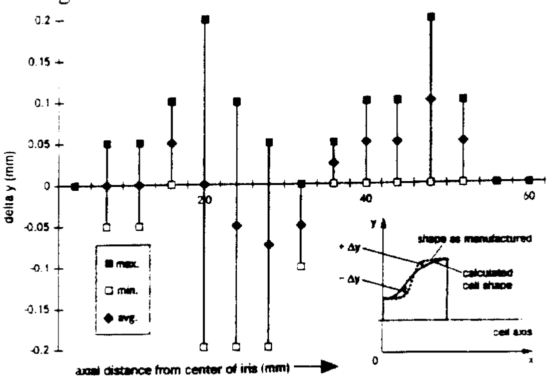

Figure 6. Deviation of cell geometry, as deep drawn, from calculated shape (avg. for 10 copper half-cells).

The experience gained during the manufacture of the Cu models will be transferred to the fabrication of the first two full size 9-cell Nb cavities for TESLA which are presently under production. The main design change as compared to the Cu models will be stiffening rings between the steep slope of the cells near the irises in order to increase the mechanical stiffness of the structure especially with respect to the expected Lorentz forces during beam operation.

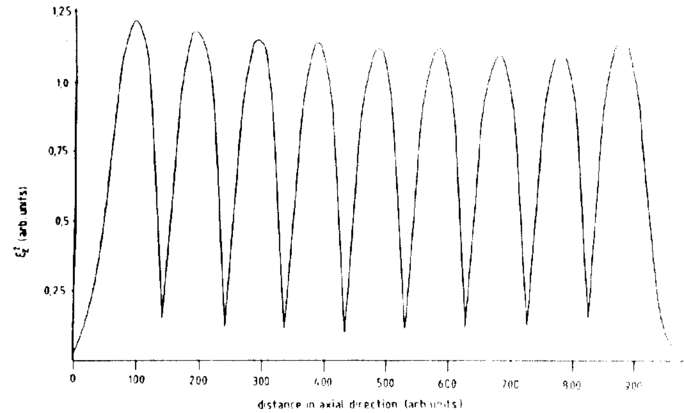

Figure 7. Field flatness of TESLA RF models (courtesy of DESY Hamburg).

III. CONCLUSION

From the experience gained in the described cavity projects we trust that we derived the necessary know-how in order to meet the challenging tasks of future large scale cavity production which has to meet demands for high accuracy as well as low cost. It seems essential to us that already in an early stage of cavity design industry will be involved in order to find a reasonable compromise between the scientists' demand (which mostly is at the edge of what is physically achievable) and the requirements of the manufacturer in order to arrive at a cost-effective product.

IV. ACKNOWLEDGEMENT

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