Production of Superconducting Niobium Cavities for CEBAF

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ABSTRACT

In 1989 the US South Eastern University Association SURA contracted Interatom for the production of 360 superconducting 1.5 GHz niobium cavities for the Continuous Electron Beam Accelerator Facility (CEBAF) in Virginia. The production of these cavities includes the manufacturing from niobium material of RRR ≥ 250 for the cells, the rf optimisation of frequency (± 100 kHz), field flatness ($\Delta E/E \leq 2.5$ %) and external Q of the fundamental mode couplers (± 20 %) and a final machining to fulfill the dimensional requirements. After a pre series production of 14 cavities with a rate of 2 to 3 cavities per month the series production has started with a rate of 12 cavities per month in October 1990. Until April 1991 in total 102 cavities have been delivered to CEBAF on time. After a final preparation at CEBAF accelerating fields up to 18 MV/m and Q values in the 10^{10} range have been measured at CEBAF significantly exceeding the guaranteed values of $Q = 2.4 \cdot 10^9$ and $E_a = 5$ MV/m.

I. INTRODUCTION

Starting with the fabrication of 4 superconducting 1.5 GHz niobium five cell cavities, their assembly to cavity pairs hermetically sealed by kapton windows and their successful cryogenic rf tests [1] we are now fabricating in total all 360 cavities for the 4 GeV c.w. accelerator CEBAF [2].

Our special goal of this mass production project is the optimisation of all the necessary fabrication steps in respect to quality, timely delivery and cost effectiveness.

This task is based on our experiences gained in other superconducting accelerator projects like for Wuppertal, Darmstadt, Saclay, CERN, INFN, DESY, LANL a.o. [3,4].

II. GENERAL REQUIREMENTS AND FABRICATION PROCEDURES

A CEBAF cavity consists in total of about 40 niobium parts (fig. 2 and 3) which have to be manufactured, chemically treated and finally joined together by electron beam welding.

The main requirements and fabrication steps for the cavity mass production are given in the tables 1 and 2.

The reproducibility in the dimensions of the components, especially of the eb welded cells is high enough that no intermediate frequency adjustment steps of the single cells, which had been performed on the prototype cavities, are necessary during mass production.

Total number/ delivery time	360 cavities in 37 months
Material	Niobium RRR ≥ 250 for the cells RRR 20-40 (Reactor Grade) for the coupler parts both delivered by CEBAF
Surface preparation	to be cleaned by chemical etching in a buffered solution of HF-HNO_3-H_3PO_4
Welding	electron beam welding
Dimensional tolerances	± 0.05 mm for key dimensions
Frequency	f = 1497.7 ± 0.1 MHz at room temperature, in normal atmosphere before final chemical treatment at CEBAF
Field flatness	$\Delta E/E \leq \pm 2.5$ % under above conditions
External Q of FPC	$Q_{ext} = (6.6 \pm 1.3) \cdot 10^6$ under above conditions

Table 1. General requirements for the CEBAF 1.5 GHz cavities

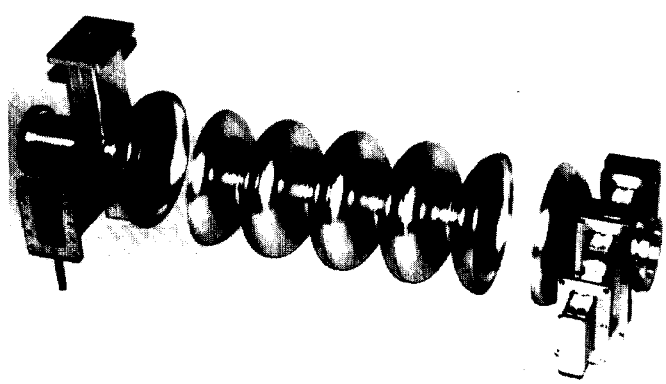

Figure 1. Arrangement of Higher Order Mode (HOM) coupler part, central cavity section and Fundamental Power Coupler (FPC) part before eb welding to a complete cavity.

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All critical steps are systematically controlled by our quality assurance department in order to detect and correct fabrication errors very immediately. As a consequence scrap could be kept in the few percent range until today.

Niobium material inspection and defect removal (if necessary)

Deep drawing of high RRR sheets to half cells	Machining of coupler components
Chemical preparation, visual inspection and defect removal(if nec.) of half cells	Partly chemical preparation, inspection and defect removal(if nec.) of subcomponents
Eb welding of half cells to a center part	Eb welding of subcomponents to couplerparts

Eb welding to a complete cavity

Inspection, defect removal (if nec.)

RF adjustment of frequency, field-flatness and Qext of FPC

Final machining

Final BCP, inspection and leaktest

Delivery to CEBAF

Table 2
Main cavity fabrication steps during mass production

III. Cavity Production Details

The niobium material for the cells with a RRR $\geq$ 250 have been contracted by CEBAF from the companies Heraeus, Teledyne Wah Chang and Fansteel. After receipt at Interatom those sheets have been visually inspected and the side which is exhibited to the rf field is defined. In some cases yield strength measurements have been performed. The chemical preparation after the deep drawing process consists of decreasing, soaking in HCL and H_2O.

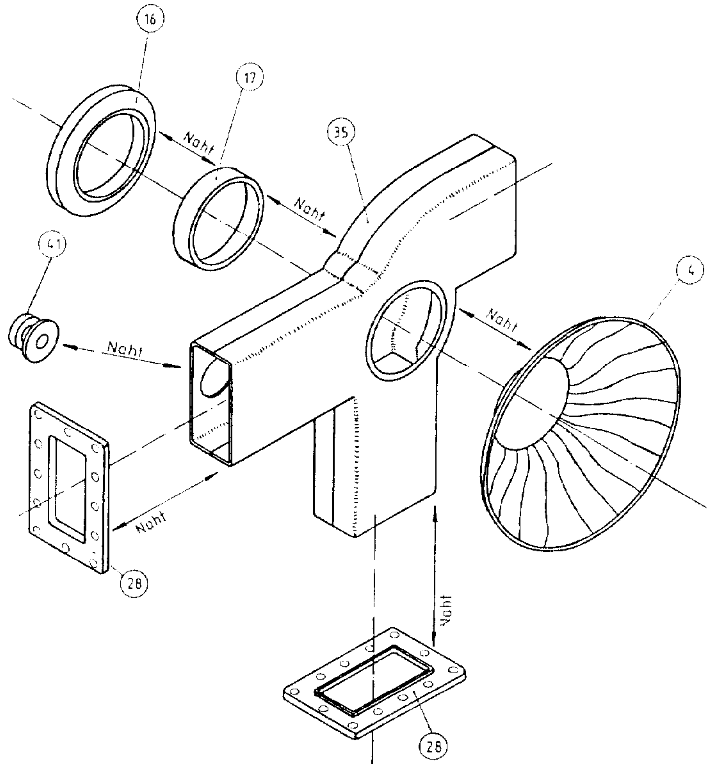

Figure 2. HOM coupler subcomponents

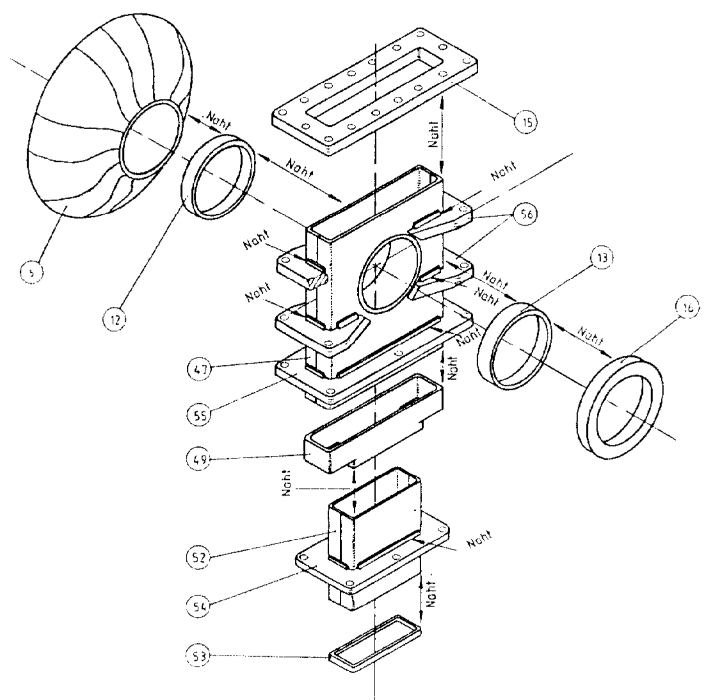

Figure 3. FPC subcomponents

Defect removal is performed with a special abrasive. The eb welding technique is described in detail in [5]. Before eb welding the respective parts are shortly chemically etched in a $HF\text{-}HNO_3\text{-}H_3PO_4$ solution, rinsed in high purity, filtered water and dried and packed under class 100 clean ro m conditions.

In the meanwhile we are able to apply the deep drawing technique also for the production of complete HOM coupler halfs (fig. 4) and FPC halfs.

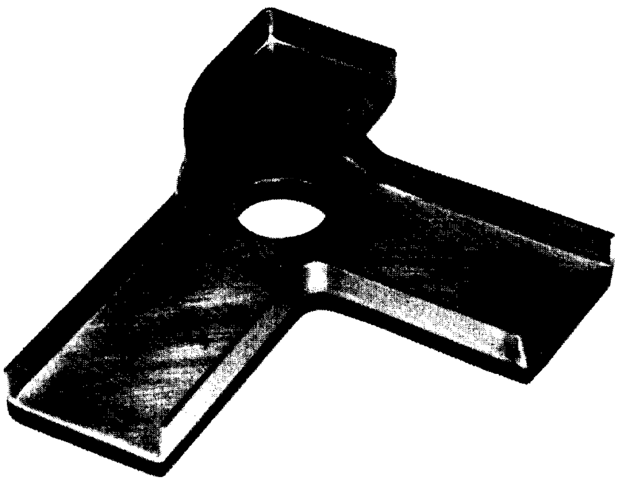

Figure 4. New developed HOM coupler half produced by deep drawing niobium sheet material

IV. RF Optimisation

The frequency and field flatness is adjusted by inelastic deformation of the cavity cells. Field profiles are taken with a HP 8753 B/C / HP 85047 A Network Analyser by measuring the phase shift at constant frequency during movement of a dielectric bead along the cavity axis.

Directly after mechanical completion of the cavity the field flatness $\Delta E/E$ is normally below $\pm$ 10 %. The required flatness $\Delta E/E < \pm$ 2.5 % and frequency is reached typically after only a few steps of inelastic cell deformation.

After systematic measurements of the external Q of the FPC in the pre production phase the key dimensions have been adjusted so that Q_{ext} values in the range around $5 \cdot 10^6$ to $5 \cdot 10^7$ are typically reached after adjustment of frequency and field flatness. Only one or two steps of inelastic coupler deformation are then normally needed to reach the required value of $6.6 \cdot 10^6$ within a tolerance of $\pm$ 20 %.

V. Final Preparation and Cryogenic RF Test

After rf optimisation the cavity flanges are finally machined within tolerances in the range of $\pm$ 0.05 mm.

At CEBAF site the cavities are inspected, finally chemically etched, mounted to cavity pairs and than cryogenically tested [6].

Until April 1991 in total 102 cavities have been delivered to CEBAF. About a third of them have been tested (until March 1991) [6,7]. Accelerating fields up to E_a = 18 MV/m and Q values in the 10^{10} range with mean values of about 10 MV/m and 0.5 to $1 \cdot 10^{10}$ for $E_{a,max}$ and Q_0 at 5 MV/m, respectively.

VI. Conclusion

Until April 1991 in total 102 from the 360 cavities ordered by CEBAF have been delivered on time. All cavities which have been tested at CEBAF until now significantly exceed the guaranteed values for accelerating field and cavity Q with mean values of about 10 MV/m and 0.5 - $1 \cdot 10^{10}$, respectively.

VII. Acknowledgement

We would like to express our gratitude to the close cooperation with CEBAF, especially with P. Kneisel.

VIII. References

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