COST REDUCTION IN CAVITY FABRICATION

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Abstract

In Europe and Japan there exist several companies which are qualified to fabricate superconducting cavities for accelerator application. Two different technologies are used: Niobium sputter coating of copper cavities or e-beam welding from solid Niobium. The first technology was used to fabricate the cavities for the LEP accelerating unit at CERN. These cavities are operated at an accelerating gradient up to 7 MV/m. At higher accelerating gradient cavities made from solid Niobium show a better performance. The required gradient of 23 MV/m at a quality factor of 1x10^10 could be demonstrated with many 9-cell cavities (1.3 GHZ) operated at the TESLA Test Facility (TTF). These cavities are fabricated from solid Niobium.

Stringent vacuum requirements must be meet during welding the Niobium parts. Furthermore the Niobium parts must be handled with great care not to contaminate the later inner surface of the cavity. These conditions result in considerable effort during fabrication. Development of complex tools or installation of specialized e-beam welding facilities are too costly for the fabrication of only a small number (less than 100) of cavities. Therefore an industrial study was launched to investigate large scale fabrication methods of Niobium cavities. This study was carried out in order to create cost numbers for the production of 20000 resonators within three years for the TESLA linear collider project.

1 INTRODUCTION

The TESLA [1] design is based on superconducting accelerating cavities. One cavity consists of 9-cells and is operated at a frequency of 1.3 GHZ. Nearly 100 of those resonators have been fabricated by 4 different European companies. The price of one complete cavity (including HOM coupler, input coupler ports, NbTi flanges and the transition to the Helium tank) is around 50.000 Euro (at 1999 price base). It includes the Niobium material as well as the fabrication. The ratio of fabrication to material is about 2/3 to 1/3.

A study was ordered from an industrial team with expertise in cavity fabrication as well as in planning of large fabrication facilities. The task was to determine the production philosophy and calculate the fabrication price of 20000 cavities as needed for TESLA. The study was structured in several parts:

(a) analyse the present fabrication technology in terms of simple, complicated and critical procedures,
(b) to work out a price profile of the present technology and identify cost driving action
(c) to propose/comment simplifications of the present fabrication and handling procedures,
(d) to work out a fabrication philosophy which is adapted to a cost effective production of 20,000 cavities over a period of 3 years,
(e) to describe the over all quality insurance management,
(f) to work out a detailed time schedule for planning, building, commissioning, operating and decommissioning of the fabrication facility needed,
(g) to describe the amount of investment and man power needed to realize the production,
(h) to determine the total cost of the production of 20,000 cavities,
(i) to investigate a distributed fabrication at several different existing companies and determine the total cost of the production of 20,000 cavities.

2 STANDARD FABRICATION OF WELDED NIOBIUM CAVITIES.

The standard fabrication process of solid niobium cavities consists of the followings steps:

(a) deep-drawing of cups from Niobium sheets
(b) e-beam welding two cups at the smaller diameter (iris of the accelerating structure) to form a dumb-bell section
(c) e-beam welding stiffening rings at the outside near to the iris curvature
(d) consecutive e-beam welding of dumb-bells at the larger diameter (equator of the accelerating structure) in order to form the whole cavity structure
(e) e-beam welding the “end-groups” consisting of beam pipes, input coupler ports, higher order mode couplers, pick-up probes and transitions to the Helium tank
(f) final e-beam welding of end groups and cavity body.

3 ANALYSIS OF PRESENT FABRICATION COSTS

The production of 6 earlier cavities at Astrium (former Dornier) was analyzed in detail. The cost breakdown into major groups is displayed in Fig. 1. One can see, that

- 50 % of total costs are determined by preparation of and conducting of eb-welding
- 36 % are determined by machining of parts
- the end groups (beam pipe, input coupler port, HOM couplers, flanges, transition to LHe container) cost as much as the 9-cells alone.

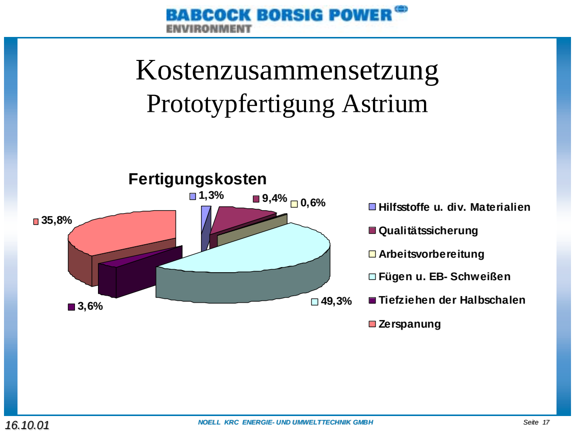

Fig. 1: Relative costs of the cavity prototype production at Astrium. (Hilfsstoffe u. div. Material: auxiliary material; Qualitaetssicherung: quality assurance; Arbeitsvorbereitung: preparation of working steps; Fügen u. EB Schweißen: assembly of parts and EB welding; Tiefziehen der Halbschalen: deep drawing of cups; Zerspanung: cutting and milling)

4 STUDY OF MASS PRODUCTION OF 20000 NB CAVITIES IN 3 YEARS.

The dominant cost of prototype cavities production is determined by the eb-welding action. The stringent vacuum requirements of 5x10^-5 mbar before starting the welding action results into a rather long pumping time. In the same way the cool-down period down to 100°C requires a long waiting time before opening the chamber. Therefore 3 chamber eb-welding facilities are planned for the cavity mass production. Furthermore special tool are anticipated in order to weld many parts in one chamber cycle. The average operating time of the eb-welding machine for one cavity is considerably reduced by theses means: 35hours per cavity in the prototype production to 5 hours in the planned mass production. Machining of parts is out-sourced to low tech companies. Quality control, cleaning and welding is concentrated at a specialized new fabrication facility. The new cost breakdown is shown in Fig. 2. As compared to the prototype fabrication the new relative costs are:

- only 10% for welding as compared to 50% in the prototype fabrication
- 77% for parts production as compared to 49% in the prototype fabrication

The production price per cavity is considerably reduced. Although the absolute number cannot be given here in order to keep competition between possible vendors, the reduction of relative costs for the welding process demonstrates the magnitude in cost savings. With this reduction in manufacturing costs the price of the Nb material becomes an important contribution to the total costs.

5 COST REDUCTION OF THE NB MATERIAL

As the production costs of the cavity fabrication is considerably reduced, it is important to look for cost savings in the Nb material. It is not anticipated, however, to lower the quality specification of the RRR300 material. Intensive discussions with Nb vendors are started to look for cost reduction items, like:

- band rolling of the sheet material instead of plate rolling with high demand of man power
- definition of only one good RF surface in order to reduce costly surface finish
- improve vacuum conditions for less melting cycles
- in house return of scrap material by manufacturing of discs instead of rectangular plates.

Another industrial study is being launched to investigate the total costs of building a new melting facility specialized to produce RRR300 Niobium. Non melting activities like forging, rolling and chemical cleaning will be out-sourced. Depending on the result of this study we invisage to found a consortium of interested companies to sign in for this enterprise.

Recently single cell cavities have been fabricated from NbCu clad sheets. At DESY a 0.8 mm Nb sheet has been bound to a 3mm Cu sheet by explosive binding technique. The first superconducting measurements of such a single cell resonator resulted in an excellent gradient around 40 MV/m [2]. This fabrication technique will considerably reduce the amount of high RRR Nb needed. But more tests with 9-cell cavities and more cooling cycles are needed to investigate any possible lamination of the composite material. Furthermore the effect of flux trapping during a quench might deteriorate the RF performance and needs more investigation.

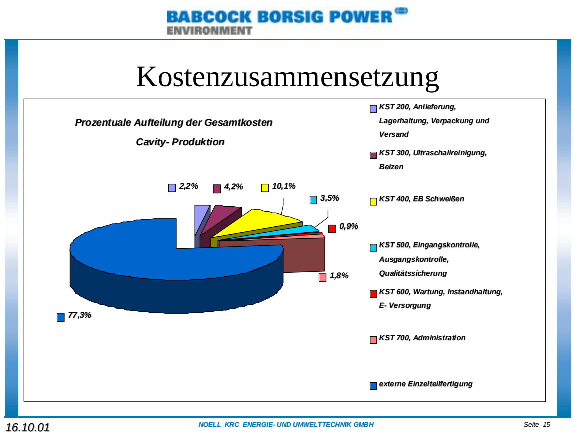

Fig. 2: Relative costs of mass production of cavities (KST 200: delivery and storage; KST 300: ultrasonic and chemical cleaning; KST 400: eb welding; KST 500: quality assurance; KST 600: maintenance, electrical energy; KST 700: administration; externe Einzelteilfertigung: external parts production

6 SEAMLESS CAVITY PRODUCTION

Spinning or hydroforming are promising techniques to form a resonator without welds at the iris or equator regime. Single cell resonators have been fabricated by both methods and demonstrated excellent superconducting performance [2]. It seems that these techniques should allow cheaper resonator production than by welding. It must be noted, however, that the dominant costs in the cavity mass production are related to the complex end-groups, which cannot be fabricated without welding. A detailed cost analysis will be conducted in the near future to determine the possible cost savings by seamless production of the middle part of the cavity. It should be noted, however, that a smooth Nb wall without welds at the high magnetic field region might allow even higher accelerating gradients as with the present welded resonators.

7 SUMMARY

The present welding technique for fabrication of Nb resonators has been analyzed and a fabrication facility for 20000 resonators has been evaluated. Considerable cost savings became obvious due to

- the use of a tree chamber welding machine
- use of tools to allow welding of many parts in one cycle
- consequent outsourcing of parts production.

Therefore the cost of Nb became an important part of the cavity production. Using NbCu clad material could reduce the amount of high RRR Nb material.

Hydro-forming and spinning technologies were used to fabricate seamless single cell resonators. The total costs of 9-cell resonators using these fabrication methods are under investigation.

8 REFERENCES

[1] TDR, TESLA Technical Design Report, DESY 2001-011, ECFA 2001-209, TESLA Report 2001-23, TESLA-FEL 2001-05, March 2001

[2] W. Singer et al, this Conference