INDUSTRIAL PRODUCTION OF SUPERCONDUCTING ACCELERATING CAVITIES FOR HERA

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Abstract: Large scale application of superconducting accelerating cavities requires industry to take part in the construction and the fabrication of those structures. Dornier has built three prototype cavities (operating frequency 500 MHz, four cells) for HERA. The fabrication did not only include the forming and welding of the niobium parts, but also the design of the helium tank, the development of joining techniques, and the complete chemical treatment. The performances of these cavities were Q_o values of up to 1.9×10^9 and accelerating fields of up to 5.1 MV/m at laboratory and beam tests at DESY. Meanwhile the fabrication of 16 more cavities has been started.

Introduction

For a long period the development, construction, fabrication, and surface treatments of superconducting cavities were a domaine of institutes, laboratories and their workshops. In the last years, since rf superconductivity seems to be mature for application in large accelerators, these activities are transferred more and more to industry. Basic technologies for this advanced field in research and development are: joining techniques: especially electron beam welding; ultra high vacuum, radio frequency and low temperature technology; knowledge of surface treatments and handling under ultra pure, dustfree conditions. The knowledge of these techniques is well installed at Dornier by participation in space research programmes. In addition an intense collaboration and partnership between DESY and Dornier was essential for the success of this development programme.

Cavity design

The layout of the cavity is shown in Fig. 1. The niobium cavity with the beam tubes, three HOM couplers, and the input coupler port is designed and calculated by DESY. For safety reasons DESY asked for an helium tank integrated to the cavity, which reduces the amount of liquid helium compared to a conventional bath cryostat. The design of Dornier resulted in a tank welded to the niobium cavity. Displacement bodies fill the largest part between the cavity and the outside wall.

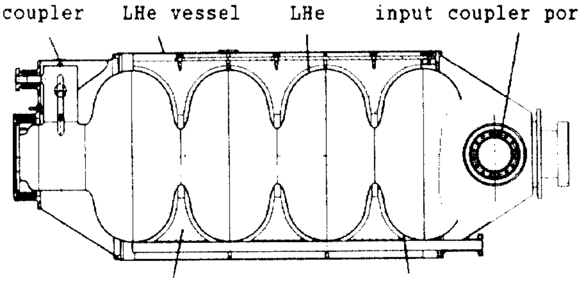

Fig. 1 Layout of the superconducting accelerator structure for HERA

This construction includes several advantages. First the liquid helium is reduced to less than 100 l per cavity. Second there are no flanges from the helium room to the isolation vacuum (except of the inlet of the LHe and the outlet of the helium gas) and to the beam vacuum. All beam line parts are connected by metal sealing techniques. This reduces the risk of dangerous leaks to this very sensitive part of the system. And third the springs which fix the distances between the cavity and the displacement bodies in addition damp mechanical resonances. The design values of the structures are given in Table 1.

frequency	500 MHz
number of cells	4
operating temperature	4.2 K
Q_o at 5 MV/m	$2 \cdot 10^9$
accelerating field	5 MV/m
Input power	< 100 kW
HOM-couplers	3 (two versions)
active length	1.2 m
liquid helium	< 100 l/cavity

Table 1 Parameters of the superconducting 4 cell cavities for HERA [1]

Fabrication

In the following the fabrication steps will be discussed briefly.

Materials

All niobium parts are made from material with an RRR of 100 ± 10, supplied by W.C. Heraeus [2]. To avoid a reduction of the Q values by external magnetic fields, the flanges as well as the LHe vessel are made from amagnetic stainless steel, european standard 1.4429. Aluminium was choosen as the filler material because it is amagnetic, light, anticorrosive, not expensive, and machining is easy.

Forming of parts

The half cells and the tapers are formed by spinning. For the stubs and the output lines of the HOM-couplers niobium tubes and rods were available. The other tube like elements of the HOM couplers were rolled, electron beam welded, and retouched.

Joining techniques

The niobium parts are electron beam welded from the outside with a defocussed beam in a vacuum in the 10^{-5} mbar range.

To reduce the risk of producing leaks during mounting, DESY required stainless steel flanges and the use of "Helicoflex"[3] sealings. During the prototype production bondings between niobium parts and stainless steel flanges have been performed by hot isostatic pressing (HIP). This process was carried out at a temperature of 1000 °C and a pressure of 1000 bar roughly. Experiments on flat samples had resulted in excellent joinings (Fig. 2).

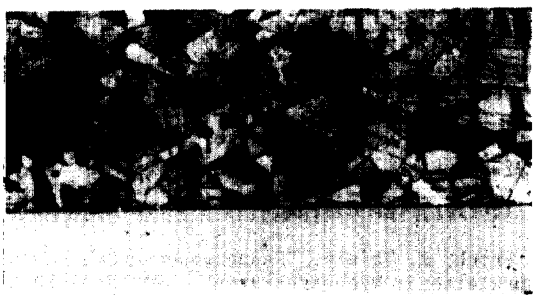

Fig. 2 Diffusion bonding by hot isostatic pressing: above VA, below Nb (magnification 240)

But during prototype production the reproducibility was not sufficient. Therefore, in the series production HIP will be replaced by a brazing technique, developed and qualified by Dornier during the prototype phase.

Surface treatments

To reach high Q- and field values, proper surface treatments are essential. Based on the developments at different laboratories[4, 5, 6,] the installations for a complete chemical treatment and dustfree handling for cavities were investigated at Dornier. Cleanrooms up to class 100 are available.

The surface treatments in between the production steps are following the procedures described in[5]. After the last electron beam welding the cavities may be tumbled (Fig. 3) to obtain a smooth surface and to remove possible beads from electron beam welding. The damaged surface layer is removed by a buffered chemical polishing (BCP). 40 l of the acids HF, HNO_3, and H_3PO_4 are filled into the cavity, which is turned around its middle iris in a specially constructed apparatus (Fig. 4).

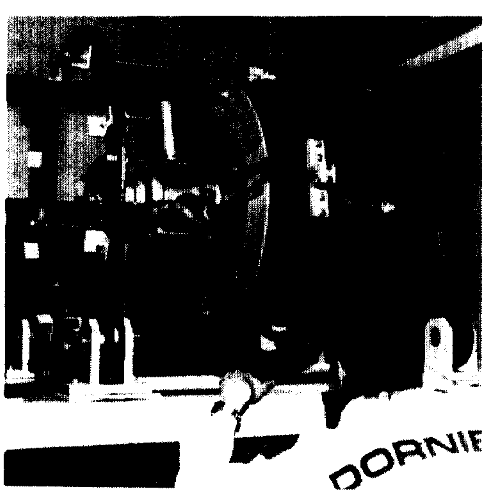

Fig. 3 Single cell cavity during tumbling

Fig. 4 Cavity installed for chemical polishing

A last BCP with fresh acids removes about 20 μm from the surface. An extensive rinsing with 16 MΩcm dust free water follows the chemical treatment. Finally the cavity is dried under dustfree conditions and a leak test is performed. For shipping the cavities are filled with filtered, dry nitrogen gas under weak overpressure.

Reproducibility

Superconducting accelerator structures require restricted tolerances with respect to frequencies and dimensions. Therefore it is asked for a high reproducibility in forming of all parts of the cavities. Controlled parameters are listed in Table 2. In total 22 shells

middle cells		
frequency, unwelded before correction	Δf =	± 150 kHz
frequency, welded and corrected by cutting at equator	Δf =	± 70 kHz
end cells		
frequency, unwelded before correction	Δf =	± 200 kHz
frequency, unwelded after correction by cutting at equator	Δf =	± 50 kHz
length of cells		
adjustment before welding	Δl =	± .05 mm
adjustment after welding	Δl =	± .1 mm
cavities		
field flatness before tuning		20 %
field flatness after tuning		< 2 %

Table 2 Parameters controlled during production

for middle cells and 8 shells for end cells have been formed in one charge each. A first tuning is performed in cutting the iris and the equator regions. These shape corrections are defined by the derivation from the design frequency using SUPERFISH [7] calculations.

Experimental results

Of course during prototype development production steps may vary. In our case different surface treatments lead to the results given below. In Table 3 the history and the results of the three cavities are listed, starting after the complete electron beam welding.

cavity	preparation	test results		limitation	comments
		Q_o (10^9)	E_{acc} (MV/m)		
I	tuning tumbling BCP	1.9	6.2	field emission	low power input coupler
I	new tuning BCP	1.3	5.1	sparking at HPW	measured before and during beam test in PETRA
II	tuning tumbling BCP	leak at beam tube flange			
II	complete end part replaced BCP	1.1	2.5	quench at equator in the repair weld	measured before and during beam test in PETRA
III	tuning BCP	1.3	5.0	field emission	low power input coupler

Table 3 Treatments and performance of the prototyp accelerating cavities for HERA (HPW: high power window)

After the final chemical polishing cavity I was mounted into the horizontal cryostat and tested to check the performance before going into the PETRA ring. Cavity II was mounted in the same cryostat to complete the module. Cavity III was mounted into the second horizontal cryostat. On this set up tests were carried out to study the performance of the cavity and of the cryostat in detail. The results of the cavity tests are summarized in Table 3. The description and discussion of these experiments are given in [8].

The results show that after a qualified course of production accelerating gradients of 5 MV/m can be reached even under the difficult mounting and operating conditions of an existing accelerator. The Q_o values are not yet satisfying. Two effects are supposed to reduce the theoretical Q_o of about $3 \cdot 10^9$ at 4.2 K: electron loading and insufficient shielding from external magnetic fields. The first is indicated by the radiation at high fields. The second will be improved by a new radiation shield.

Conclusion

The successful test of two superconducting accelerating structures in the PETRA ring has proven that the concept of these cavities is well adopted for the requirements in HERA. The sum of the tests performed on the three prototype cavities demonstrates that industry is well able to deliver superconducting accelerator structures ready for testing. Dornier is going to build 16 cavities which will be installed in HERA.

References

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