Industrial Fabrication of Superconducting Accelerators

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Abstract

During the last two years major progress has been achieved in the industrial production of superconducting accelerators. A technology program with CERN has been completed in order to transfer the technology to sputter niobium onto copper cavities. Several cavities have surpassed design values and series production for LEP 200 is in progress. Secondly a complete linac consisting of 2 single cell and 2 five cell accelerator modules has been designed and fabricated based on inhouse experience. All 4 modules have surpassed the design values (5 MV/m, Q > 2 x 10^9, cryogenic losses ≈ 3 Watt) during tests at Siemens. All 4 modules are in the meanwhile delivered to JAERI. Details and recent results of the projects are presented.

I. INTRODUCTION

Production of superconducting accelerators in the past has been conducted by the laboratories itself. The work has only been partly contracted to Industry (cavities, other components). Siemens has shown that the complete scope starting from design, followed by manufacturing, assembly, test and delivery with guaranteed performance is available from Industry.

The following gives two examples for this new development.

II. NB COATED CAVITIES FOR LEP UPGRADE

Scope of the project

The scope of this project covers fabrication of the copper cavities, chemical preparation and coating, cold rf-test at CERN, fabrication of all other components (He-tanks, tuners, vacuum tanks, cryogenic domes) and finally assembly of the complete module.

Technology transfer

With a very intense technology transfer phase the project started with the installation of a new chemical treatment plant, the sputter equipment as well as clean rooms (class 100) for magnetron assembly and final assembly of the modules and was continued by establishing all the necessary procedures in close collaboration with CERN. The development of the coating procedure is described in [1], [2], [3].

Test results

After coating at Siemens all the cavities are tested in a vertical cryostat at CERN. Up to now 12 Siemens-cavities have surpassed the design values of Q_0 (at 6 MV/m) > 4 x 10^9. The summary of all accepted cavities up to now is shown in figure 2. Investigations on the copper base material resulted in a change of the chemical preparation procedure. After increasing the thickness of the layer removed by electropolishing (from 60 µm to 120 µm) all test results significantly have improved (cmp. figure 2).

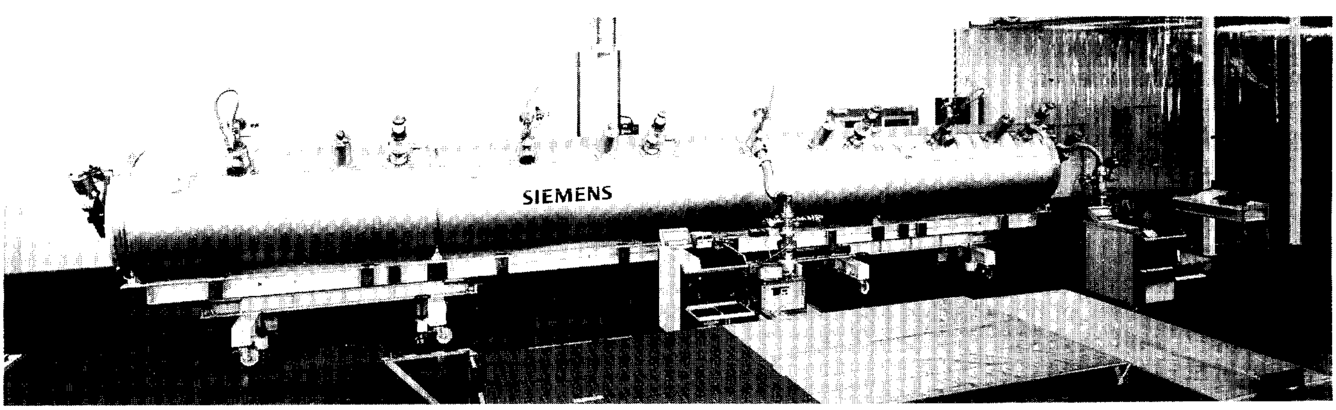


Fig. 1: One completely assembled superconducting accelerator module for LEP Energy upgrade

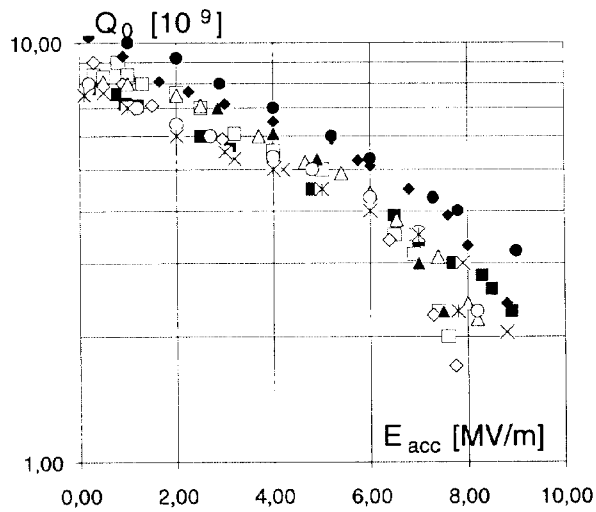


Fig. 2: Results of the 12 accepted cavities (vertical test)

The 4 cavities which have passed the acceptance test first were assembled to a module (figure 1) and send to CERN for cold test in December 1992. Unfortunately a leak in one of the beamtubes supplied by CERN and assembled to the module lead to an uncontrolled air-filling and a deterioration of the cavity performances. A repair cycle which includes diassembly, clean water rinsing (High pressure or normal pressure) and re-assembly at Siemens is in progress. One of the 4 Cavities has already been rinsed and passed the specification.

III. 4 TURNKEY ACCELERATOR MODULES FOR JAERI FEL EXPERIMENT

In 1/91 the contract for the delivery of 4 superconducting 500 MHz accelerator modules was concluded. The contract covered design and layout, manufacture and cold rf test of the two single cell modules and the two five cell modules.

Design and Layout

The purpose of the accelerator modules for the FEL-experiment and the special mode of operation (pulsed rf-mode 1 - 3 % duty cycle) required a different approach to the cryogenic design.

As the rf-losses are only 0.5 to 1.5 Watt (five cell cavity) the accelerator module is dominated by the standby losses. The design thus aimed to minimise the cryogenic losses below 4.5 Watt per module. By choosing a duplex heat shield cooled with closed loop refrigerators (20 K/80 K) the standby losses could be minimised to about 3 Watt at 4.2 K. The table below summarizes the achieved results.

For the He-tank a closed loop recondensor could be used (10 Watt) thus avoiding a central refrigerator with LHe-transfer line.

Development

Following a former contract were Siemens produced an accelerator module with a variable power coupler (400 MHz single cell module) [4] an improved power coupler with variable coupling factor for 500 MHz cavities was developed and manufactured for the modules.

It could be demonstrated that the coupler allows adjustment of the external Q for about 3 decades $3.0 \times 10^5 < Q_L < 2 \times 10^9$ with the antenna length (fig. 3).

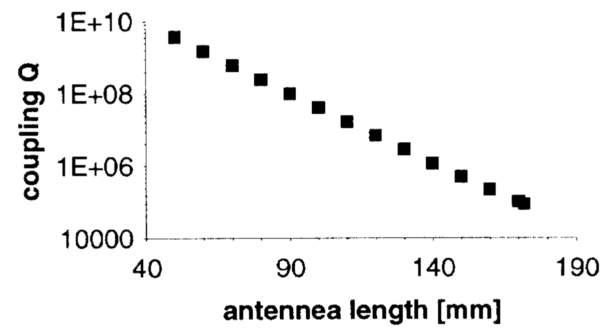


Fig. 3: External Q vs coupling antenna length for a supercondcuting 500 MHz single cell module

Manufacture

Manufacturing of the modules comprised the fabrication of all components (cavities, He-tanks, vacuum tanks, tuners, couplers), chemical preparation and assembly in clean condition. A cross-section of the five-cell module is shown in figure 5.

RF-Test

The cold rf tests have been performed as acceptance tests before shipping the modules to JAERI with the following results:

Module	Type	Q (at 5 MV/m)	Eacc max (at Q = 1×10^9)	Cryostat standby losses (4.2 K)
1	1 cell	2.5×10^9	7.3 MV/m	3.6 W
2	1 cell	2.1×10^9	6.8 MV/m	3.0 W
3	5 cell	2.2×10^9	6.4 MV/m	3.5 W
4	5 cell	2.0×10^9	6.4 MV/m	3.5 W

The maximum fields have been obtained after only a few minutes of Helium-processing and are limited by electron field emission loading in all cases.

After installation of the 4 modules on site by JAERI and connecting the beamlines, rf-feeds etc. the modules were tested again and after few minutes of rf-processing the performance as shown at Siemens could be achieved again or slightly surpassed.

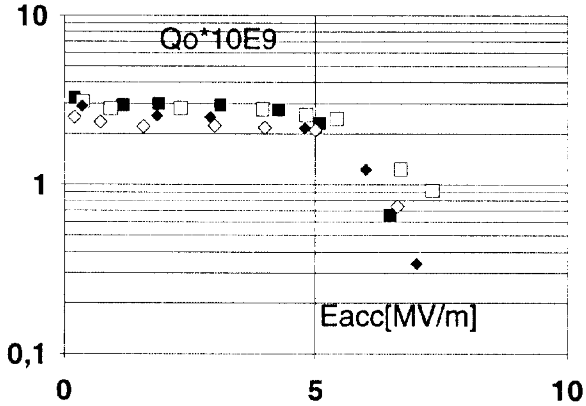


Fig. 4: Performance of the 4 JAERI accelerator modules during acceptance test before shipment

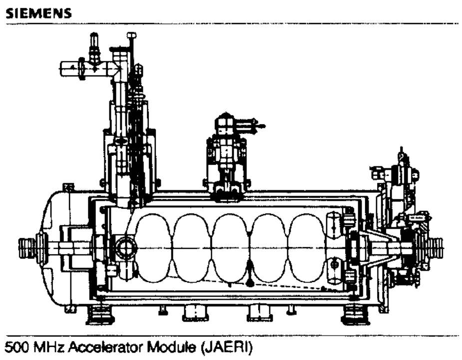


Fig. 5: Cross section of the five cell accelerator module

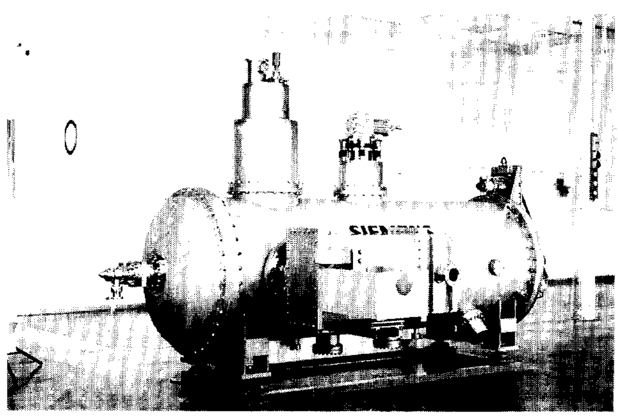
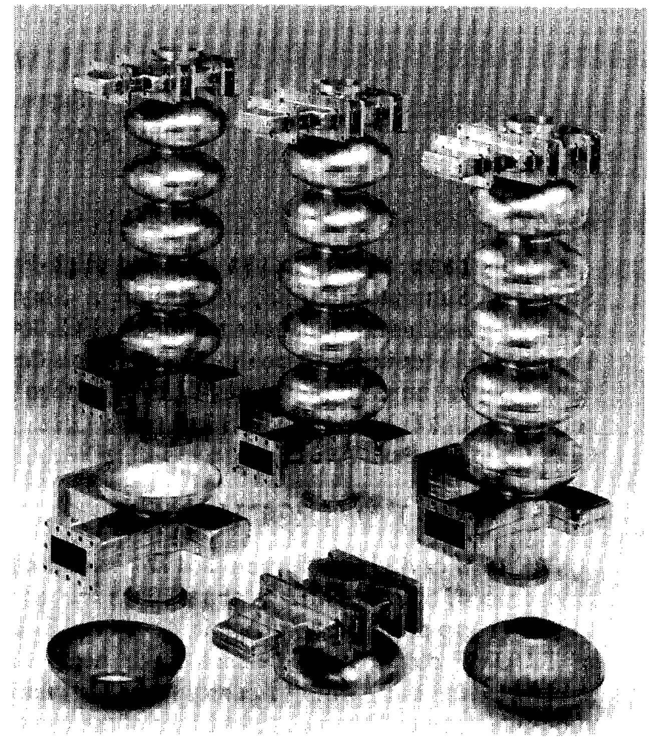


Fig. 6: The five cell module completely assembled before shipment to JAERI

IV. 360 Cavities for CEBAF

In March 1993 the delivery of 360 cavities for CEBAF has been completed as scheduled. All cavities are delivered tuned to correct field profile frequency and Q_{ext}.

They receive their final chemcial preparation at CEBAF, two cavities are assembled to "pairs" and tested in vertical cryostats prior to assembly into the cryomodule (beam-line cryostat).



Over 250 cavities have been assembled and tested at 2.0 K. The guaranteed performance is $Q_0 = 2{,}4 \cdot 10^9$ at 5 MV/m. More than 50 % of the vertically tested cavities demonstrate usable gradients greater than 10 MV/m. Details of the test and statistics on the results are given in [5].

V. SUMMARY

Superconducting cavities have been choosen as the accelerators for several projects. It could be shown that industry is well equipped and able not only to produce bare Nb-cavities (CEBAF) but also complete accelerator modules (LEP, CERN) as well as completely designed, manufactured and tested turnkey Modules (JAERI-FEL) ready for operation.

VI. REFERENCES

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