Industrial fabrication of the Superconducting HERA quadrupole coil

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Abstract

The superconducting quadrupole coils for HERA had been developed and successfully tested as laboratory prototypes by CEN-Saclay under contract of DESY, Hamburg. We report on the fabrication under industrial conditions and on test results of collared preseries and series coils. Special emphasis is laid on the consequences resulting from slight but relevant changes in material properties for the series compared to the prototypes like mechanical tolerances, permeability, insulation thickness or sensitivity to temperature during curing.

Introduction

The HERA proton ring needs more than 220 superconducting quadrupole magnets to focus the proton bunches. Interatom/Siemens in late 1986 got the contract for the fabrication of 122 quadrupoles, 31 of which have a different length compared to the standard of 1.861 m. Under contract of DESY the magnets had been designed and 4 prototypes had been built by CEN-Saclay, France. The fabrication know-how was to be transfered from CEN to industry within a preseries of 5 magnets.

Fabrication

An overview on the quadrupole fabrication is given in table 1 including quality assurance measurements.
The superconducting cable is of the Rutherford type with 23 NbTi/Cu-strands and 9.5 $\pm$ 0.03 * 1.5 $\pm$ 0.02 mm (**average**) outer dimensions. The short sample critical current is above 6900 amps (5.5 T, 4.6 K)

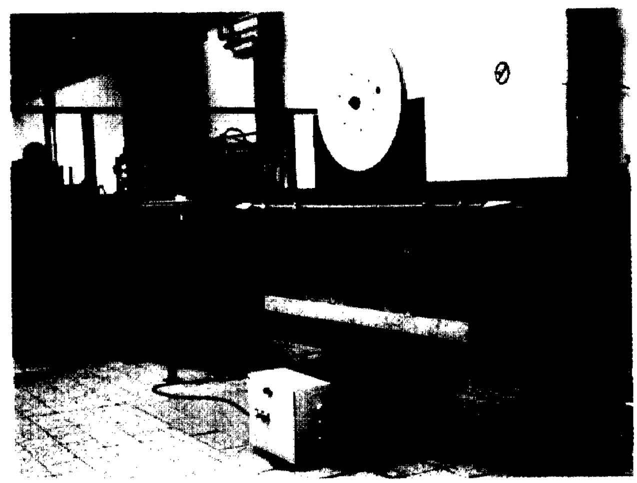

Fig. 1: Winding machine

Table 1: Overview on the HERA quadrupole fabrication

Fabrication Step	Material	Tools	Quality Assurance Measurements
I Winding of two* layer coil * first layer is cured second layer is wound on top	- Rutherford type s.c. cable with Kapton plus prepreg insulation - GFRP and copper spacers	- winding machine - mandrel	- winding tension - geometric dimensions
II Curing total duration about 6 hours/coil		- mould 1. layer - mould 2. layer - curing press - central heating system	- total length - Young's modulus - resistance, shorts - self-inductance - temperature - air moisture
III Assembling and Collaring a quadrupole out of 4 coils	- Kapton reinforcements - collar sheets from 1.4429 stainless steel (fine blanked)	- mounting table - collaring press	- resistance, shorts - high voltage test, 1 KV
IV Contacting and end Collaring	- collar sheets with "nose" - keys - end caps	- turnable hold structure	- total length - resistance - high voltage test 5 KV to mass
V Warm field measurement		- field probe device (DESY supply)	- 26 values per quad. - data transfer to DESY and CEN - cold test at CEN

The winding machine is designed with stationary storage spools and rotating mandrel, fig. 1. For the series fabrication the spool with the cable for the second layer was mechanically fastened on top of the laminated mandrel to facilitate guiding of the cable. For the prototypes the spool was hanging from above and had to be turned around by hand with each winding.

The specified insulation consisted of two layers of 25 micron kapton tape wound with 49 % overlapping and b-stage prepreg glass-fiber tape with 21 % epoxy resin content. The cable we received was within the geometric tolerances, but compared to the cable used at CEN for the prototypes the dimensions were at the upper limit.

After winding the very first layer it was found that the mould of the curing press could not be closed completely. To overcome the problem several tests were made with one or two kapton tapes of different thickness in combination with different contents of epoxy resin in the prepreg tape. After intense discussions a two tape insulation was thought to be more reliable. As a result the thickness of the kapton tapes was reduced to only two times 12.5 microns. 24 % of epoxy resin was found to fulfill all demands on the stiffness, helium transparency and shape of the coils.

The reduced thickness of the kapton tapes, however, led to unexpected shorts within the first following coils after collaring. Local reinforcements and a slightly adapted shape of some spacers were successfully introduced to exclude further problems.

During curing the coils are kept at a temperature of 160° C for 2 hours. Within a temperature - instead of time - controlled procedure the coils are shaked three times to settle the windings mechanically within the mould as long as the prepreg has not yet finally reacted.

A suitable mould release was found to minimize the excess of epoxy resin on the mould.

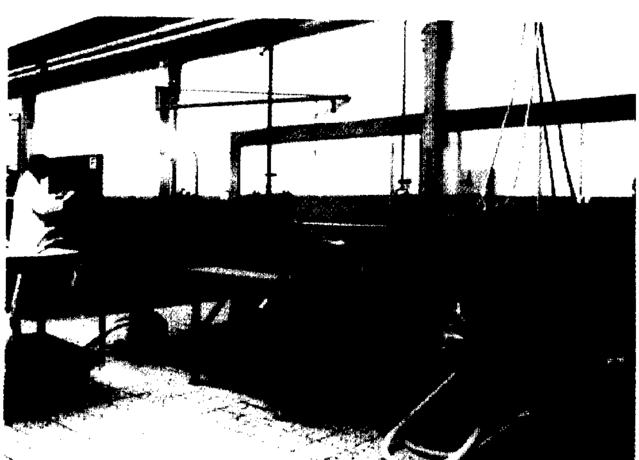

Fig. 2: Curing presses

In addition to the descriptions received from CEN/DESY /1/ drawings were produced in our shop where the specific component is shown in colour photographs. In the drawings it is pointed to special materials and handling. This procedure proved to be very helpful to assure correct execution of each step during winding and assembling.

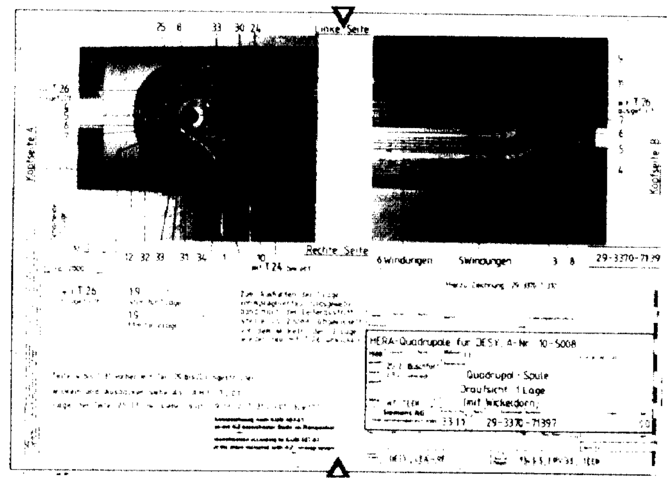

Fig. 3: Fabrication drawing

The magnetic permeability of the AISI316L austenitic collar sheets to be used for the preseries quadrupoles was measured to $1.02 \le \mu \le 1.08$. The specified value was $\mu \le 1.02$. The material had been ordered by CEN with the same specification as for the prototypes. The higher permeability, however, could not be accepted with regard to field quality. Besides one magnet with "$\mu = 1.08$" collar sheets the preseries fabrication continued with material DESY could supply from other resources. For the series quadrupoles a new melt of steel DIN 1.4429 corresponding to AISI316LN with small tolerances in the content of relevant elements was ordered. Before fine blanking DESY arranged a cold test of sample material to guarantee collar sheets with $\mu \le 1.02$. During this period the series production was continued with winding coils in stock. The material problems of course demanded for a lot of changes in planning of personnel and logistics.

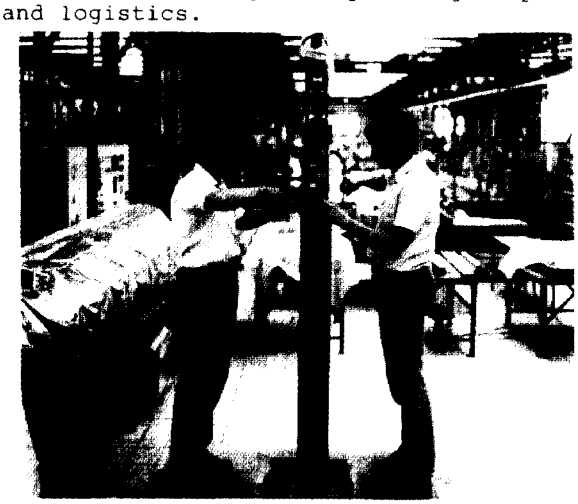

Fig. 4: Collaring of a quadrupole

We would like to mention that the development of new solutions and final fabrication procedures have been jointly decided on in a very cooperative manner by CEN, DESY and our group.

Test results

With the before described changes in material and fabrication all preseries as well as the first series quadrupole were successfully cold tested at CEN. The series quadrupoles up to now according to warm field measurements were all within the specified tolerances of the field harmonics. Along with series production more quadrupoles will undergo cold test at CEN before being mounted into their cryostat.

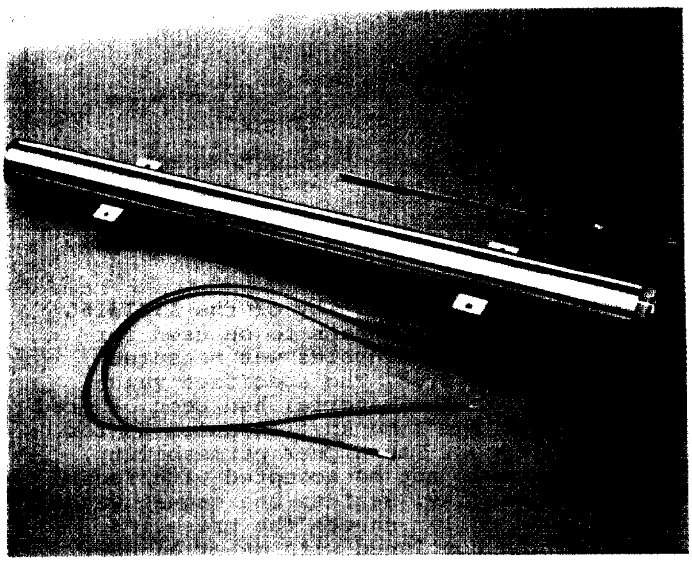

Fig. 5: Quadrupole completed with collar sheets, end caps and current leads

Reference

/1/ S. Wolff, J. Perot et al Request for Proposal of DESY B2.917, specification of the HERA quadrupole coils, DESY, Hamburg, June 1986