MAGNET MODULE FOR HERA ELECTRON RING

H. Kaiser
Deutsches Elektronen-Synchrotron DESY
2000 Hamburg 52, West Germany

Summary

The 416 half cells of the magnet structure for the HERA e-ring are built as "magnet modules", about 12 m long each consisting of dipole, quadrupole, sextupole and correction dipole mounted and prealigned on a common tubular girder. This magnet module, fitted with vacuum chamber, lead shielding, cooling piping, etc. is transported into the ring tunnel and aligned there as a unit. Technical and some economic details are described. Emphasis is on the dipole-girder unit.

Description of Magnet Module

Overview

The e-ring magnet module (Fig. 1), being rather slender, obtains its stiffness from a ca. 9 m long slitted square tube inside which is situated the dipole (Fig. 2). Four nonmagnetic "key plates" locally close the slit and nearly give the tube the deformation properties of an unslitted tube. Attached to one end of this tube is a shorter girder which holds quadrupole (Fig. 3), sextupole (Fig. 4) and the correction dipole all properly aligned relative to the dipole. Each module requires only one floor-mounted support beneath the quadrupole on which the module rests with 2 vertical-adjustment screws. With the dipole-end the module rests with 2 additional vertical adjustment screws on the neighbouring module.

The magnet yokes are made from fine-stamped laminations of 5 mm thick hot rolled magnet-iron (refer to Table 1 for magnetic properties). The dipole yoke laminations are held in place by longitudinal rails (2 in front, one in the back of the c-shaped lamination) which are welded to the prefabricated support girder by 39 short tubes. The yoke is curved to follow the beam. The quadrupole and sextupole yokes are bolted together from laminated quadrants and sextants respectively which are reenforced by steel profiles welded to them and are aligned at their junctions using the stamped contour. The correction dipole is stacked from c-shaped laminations.

For excitation the dipole uses a single extruded AI-bar which is water cooled via a stainless steel tube crimped into a groove in the extrusion. It is electrically insulated against the yoke by a glass reenforced epoxy tube. A compensation current, equal and opposite to the excitation current, flows in two similar AI-bars so situated in back of the magnets that their field nearly cancels that of the dipole excitation bar where it passes in back of the other magnets. Without compensation the maximum excitation current would produce a magnetic field of ca. 1 Gauss at the nearest private residences-about thrice the field for intolerable color changes in television pictures. The quadrupole has conventional coils of hollow copper profile with direct water cooling and glass-epoxy insulation. Sextupole and correction dipole have copper coils indirectly cooled by water and air respectively.

Quadrupole, sextupole and correction dipole are positioned properly with respect to the dipole by bolting them with surfaces produced by stamping - and therefore very accurate - to supports aligned and welded to the module girder during fabrication of the dipole yoke.

To install the vacuum chamber, one half of each the quadrupole and the sextupole are removed, their other halves remaining fixed to the module to retain alignment. The 4 reenforcing key plates over the longitudinal slot of the dipole girder are removed and the vacuum chamber, complete with lead radiation shielding is installed. Thereafter the magnets are reassembled.

Vacuum tube- and electrical connections of dipole and quadrupole circuits are situated at the ends of the module.

Discussion of Selected Characteristics

Accuracy of Shape of Dipole Yoke. In order not to loose too much aperture for the beam, the axis of the gap should follow the ideal particle orbit within a tolerance of ±1 mm both radially and vertically. Total twist should be no more than 2 mrad. To reach this goal, the yoke laminations with the shims of the pole faces locate and are pressed longitudinally on a stacking rail having the curvature of the ideal orbit and the negative forms of the sag and twist produced by gravity in the installed magnet (8 mm and 0.3 mrad respectively in the middle of the dipole). In this way, the dipole, when installed, will be straight in its side view and untwisted except for statistical fabrication-induced errors.

Statistical fluctuation of the yoke shape is minimized by a number of measures: The prefabricated slitted girder tube is stress relieved with the toothed key plates installed. After the tube is slid over the yoke, the key plates are reinstalled and the local connecting tubes are welded observing a particular sequence to minimize distortion. For the first industry-produced dipole the gap axis varied from ideal shape by ±0.35 and ±0.6 mm vertically and radially respectively. Total twist was 2.5 mrad. A test showed, moreover, that the shape of the axis varies only by ca. 0.1 mm under removal and subsequent replacement of the key plates. This satisfactory result may be attributed to a good fit between the teeth of the key plate and those of the bars fixed to the girder tube between which it is clamped with bolts (cf. Fig. 2). For the teeth standard rack-profile is used.

Tilt Alignment. On the finished module so adjusted on its supports that the ends of the dipole have equal tilt, the dipole-tilt is mechanically measured in 10 equally spaced positions along the magnet. The quadrupole tilt is then adjusted equal to the average of the dipole tilt. In the tunnel the quadrupole tilt is made to coincide with the machine plane. After this, the tilts of the ends of the dipole are again made equal. This is possible, since the dipole is relatively weak under torsion.

Bar Conductors and Insulating Tube. The rather stiff extruded AI-excitation bar must be sufficiently straight and free from twist to permit its being slid into the yoke with the insulating tube installed. This requirement has been met. There are expansion elements in the excitation- and compensation conductors which were successfully fatigue-tested simulating the maximum temperature induced change in length 4000 times by mechanical means. The conductors of neighbouring modules are electrically connected by welding short pieces of bar material over their ends.

The insulating tube, for cost reasons, is fabricated separately from the excitation bar by "pulltrusion". Polyester-glass fiber composite is customarily used for this process but will absorb so much water that unsatisfactory insulation resistance would result. The subsequent use of epoxy-resin resulted in a resistance of the insulation after 24 hours of water immersion of an acceptable value of 25 MΩ for one magnet.

Magnetic Characteristics. At first, the measured field homogeneity did not completely agree with the calculated one. Small changes to the shape of the pole contour produced the radial field dependence of the dipole shown in Fig. 5 (solid curve). Within the required "good field region" of ±40 mm the field is seen to be homogeneous within 2×10^{-4} for all energies if the superimposed quadrupole field is subtracted (dashed curve). This quadrupole is due to an apparently systematic deformation of the laminations during punching and - if sufficiently uniform over the series - harmless for the optics.

On the basis of the variation over the first 10 magnets of the measured field integral along the beam, it will be decided whether mixing of yoke laminations is required for more uniform magnet strength.

DESY's Role in Building of Magnet Modules
Magnet development, Tooling

Design of the magnet module and the tooling for producing the module girder-dipole unit was entirely carried out by DESY. After the tooling had been built, 3 experimental magnet modules were fabricated and tested at DESY, the quadruples, sextupoles and correction dipoles being delivered complete by industry.

The stacking and welding fixture (Fig. 6) consists of a very rigid basis tube on which is mounted and adjusted a rail for stacking the laminations. A hydraulically operated carriage riding on the rail compresses the stack after each addition of a new block of prestacked lamination with the lamination handling device (Fig. 7) capable of lifting lamination blocks directly from their transport box. The stacking fixture is equiped with devices to reproducibly, and without measuring position the locating surfaces for quadrupole, sextupole, correction dipole and the neighbouring modules before they are fixed to the girder by welding.

The whole fixture rests on 2 large rings for rotating it for achieving optimum welding positions.

After the development work the tooling and fabrication experience were given the industrial firm that now is building the series.

Series Production

The module girder-dipole yoke units are equipped by their builder with the insulating tubes as well as the excitation and compensation conductors.

These units are shipped to DESY, magnetically measured and there fitted by DESY personnel with the additional already magnetically measured magnets. After quadrupole adjustment, as already described, the vertical and radial location of the sextupole is controlled and corrected with shims, if necessary. Upon installation of vacuum chamber, water piping and various control devices final electrical, hydraulic and functional checks are made before the magnet-module is transported into and installed in the ring tunnel.

Economic Aspects

Compared to a more conventional magnet structure, such as that of PETRA, the magnets require about 3 times fewer floor supports and adjustment elements. Much assembly - and test work formerly executed in the ring tunnel can be done in shops outside with optimum access to the necessary facilities for assembly and inspection. Transport - and surveying operations in the tunnel are also reduced. The total installation time can therefore be shortened.

For the dipole the yoke iron, the yoke-girder unit, the conductor bars and the insulating tube are fabricated by a steel maker, a ship builder, an electrical firm and a plastics firm respectively - each optimally suited for economical production of its magnet part.

All facts taken together there is a saving of about DM 1000,-per magnet module installed and aligned in the tunnel as compared to a PETRA-like structure[1].

Current Status

The various characteristics of the magnet module have been tested so that the go-ahead for the series production has been given. Ultimately 2 modules per working day will be produced. To date 3 experimental modules have been built by DESY and 2 industry built modules have been delivered. By Oct. 1, 1987 all 416 magnet modules are scheduled to be delivered.

Acknowledgement

The author is grateful for support and critique received from many colleagues at DESY, other institutes and in industry.

References

1. H. Kaiser, Magnetmodul für HERA Bogen, DESY HERA 80/07

Minimum values of induction:

H(A/m)	50	100	500	1000	5000	10000	25000
B(T)	0.20	0.80	1.1	1.5	1.7	1.8	2.0

Permitted variation of induction:

For 90% of the measured samples B/B_o (B_o being the series-production minimum value) must not exceed the following values:

H(A/m)	50	100	1000	10000
B/B_o	0.6	0.3	0.04	0.02

The coercivity, after excitation to 10000 A/m must not exceed 70 A/m. At least, 90% of all measured samples must vary by no more than 15 A/m.

Table 1 Specified magnet properties of yoke iron

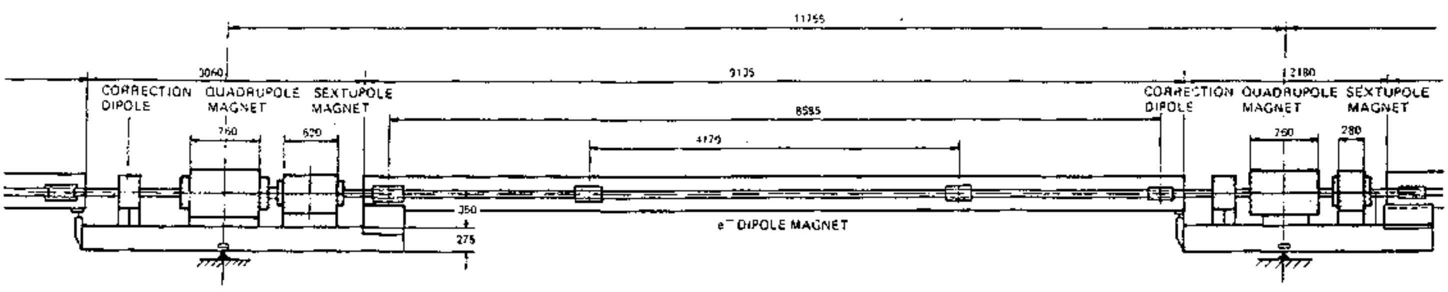
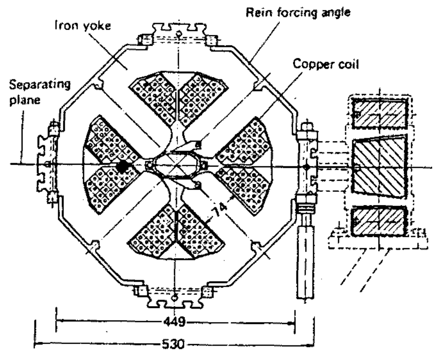


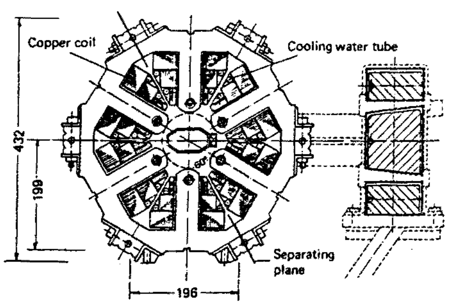
Fig. 1 Magnet Module for e-Ring



TECHNICAL DATA at 30 GeV

field gradient	0.1314 T/cm
bore diameter	74 mm
conductor (copper)	13.3x13.3 mm^2
hole diameter	5.7 mm
turns per coil	20
current	358 A
power	2.73 kW
mass	1020 kg

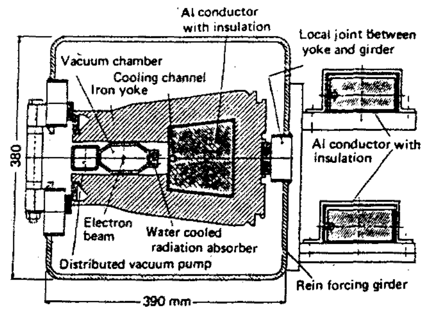
Fig. 3 Quadrupole Magnet



TECHNICAL DATA at 30 GeV

Sextupole strength	0.0409 T/cm^2
bore diameter	96 mm
conductor ribbon (copper)	28x0.5 mm^2
turns per coil	138
current	45 A
power (620 mm long magnet)	3.5 kW
mass (620 mm long magnet)	550kg

Fig. 4 Sextupole Magnet



TECHNICAL DATA at 30 GeV

Field strength	0.1638 T	Number of turns in coil	1
Bending radius	610.4 m	Current	6767 A
Gapheight	51.5 mm	Power	2.57 kW
Good field cross section	40x80 mm^2	Mass (including girder for quadrupole and sextupole	4200 kg
Conductor (aluminum)	100 cm^2		

Fig. 2 Dipole Magnet

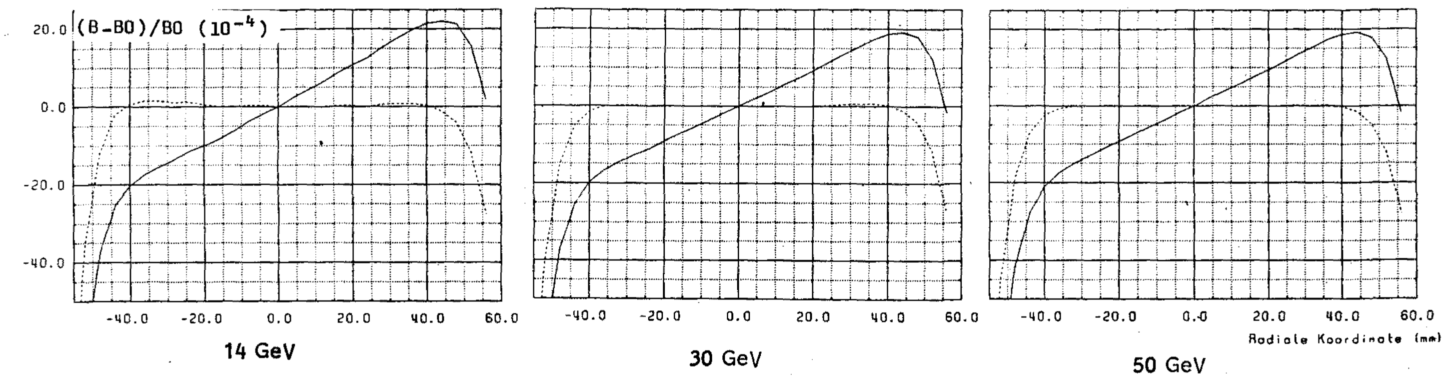


Fig. 5 Radial field dependence of dipole

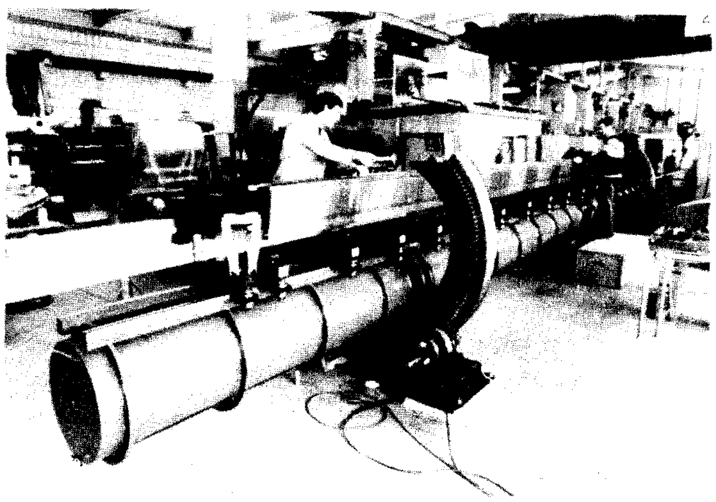


Fig. 6 Stacking and welding fixture for dipole

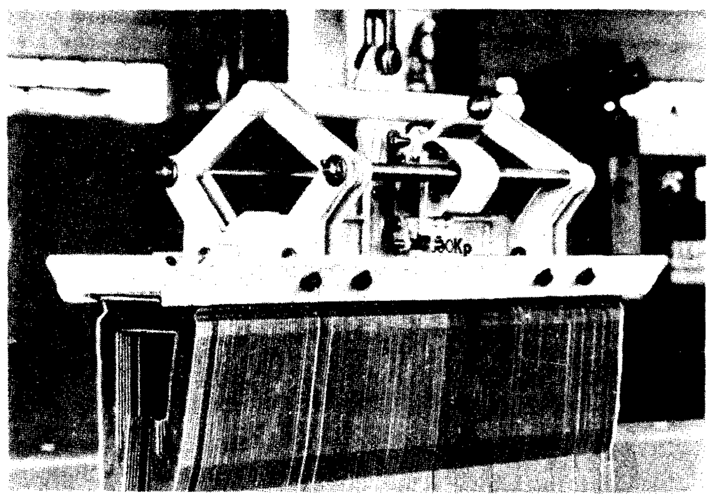


Fig. 7 Lamination handling device

Discussion

Э.А.Мяэ. Могли бы вы сравнить конструкцию ваших магнитов с магнитами ЦЕРН для проекта LEP?

H.Kaizer. The yoke of the LEP dipole would be transversely unstable if densely packed. Therefore the known concrete construction is necessary. In HERA, on the other hand, a densely packed yoke is still sufficiently stable and makes full use of iron / 15 kG in backleg of yoke/.