A Spectrometer Magnet for the HERA-B Experiment

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Abstract

HERA-B is a B physics experiment using an internal target in the HERA proton ring for the detection of CP-violation in the B system. Its detector needs a dipole magnet with an acceptance volume of approximately 20 m^3 and a magnetic field line integral of $\int Bdl$=3.3 Tm along the proton beam axis. These requirements can be satisfied with a magnet consisting of an iron yoke and a pair of superconducting coils with a total current of 2.5–3 MA-turns per coil. Since the magnet should not interfere with the present HERA operation, its effect to the beams must be compensated by special windings.

1 INTRODUCTION

The main goal of the HERA-B experiment is the observation of the CP-violation in the decay $B_0 \rightarrow J/\psi K_s^0$. A wire target is placed in the halo of the HERA proton beam to produce the B_0 mesons. The mesons decay within a few millimeters and the resulting K_s^0 after about 2 m flight path. The spectrometer dipole magnet enables the momentum analysis of the charged decay products, and its location and size are optimized for this purpose. The main parameters of the magnet are listed in Table 1. Some of the requirements are optional, such as the horizontal accessibility of ±550 mrad for changing defective detector panels without dismantling the iron cage. The discussion of the final design is still in progress and therefore several design options are presented.

The magnetic field homogeneity within the aperture is not very crucial, although the magnetic field component in the bending plane should not be too high. There may be requirements to reduce the field component parallel to the bending plane in order to improve tracking precision of the detector. An overriding condition is the non-interference with the present HERA operation, which provides luminosity for the e-p collision experiments H1 and ZEUS and polarized electrons for HERMES.

2 CONVENTIONAL SOLUTION

A conventional, normal conducting solution of this problem was first considered. Using the components from an existing magnet, the geometry of this magnet would be that presented at the left hand side of Fig. 1.

However, this solution has some disadvantages. The needed iron yoke, essential to minimize the required A-turns, is very massive, 840 tons. Moreover, the power consumption of the magnet would be more than 2 MW.

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Table 1: Magnet parameters

Length of magnet (in beam direction)	4.0 m
Distance of magnet center from target	4.5 m
Bending plane acceptance	300 mrad
Non-bending plane acceptance	160 mrad
Field integral along the beam axis	3.3 Tm
Opening angle for installations (horiz.)	550 mrad
Horizontal field integral	<0.3 Tm
Stray field integral, upstream	<0.015 Tm
Stray field integral, downstream	<0.025 Tm

3 SUPERCONDUCTING SOLUTION

For the superconducting magnet, additional A-turns are less expensive than extra iron. For the required field and acceptance volume a yoke of about 200 tons of iron should suffice. However, some more iron is needed for shielding purposes to satisfy the stray field requirements.

3.1 *Design of the magnet*

We consider two coil geometries, namely round and trapezoidal. The round coils have better force structure and lower stray fields, whereas the trapezoidal coils have better field quality.

The iron cage surrounding the coils is used for shielding purposes, but it will also shape the magnetic field and gives a relatively large contribution to the magnetic field intensity, thus reducing the needed A-turns in the coil. The design of the iron cage with both coils is shown in Fig. 1.

Table 2: Main parameters of the two designs

Coil type	round	trapez.
Main field integral	3.3 Tm	3.3 Tm
Central field	1.37 T	1.51 T
Current	3.15 MA-t	2.5 MA-t
Max. field on conductor	6.7 T	5.7 T
Stored energy	59 MJ	80 MJ
Inductance	0.98 H	2.1 H
Conductor volume	0.377 m^3	0.788 m^3
Magnet gap height	1.93–2.58 m	1.93–2.58 m
Weight of iron	550 tons	550 tons

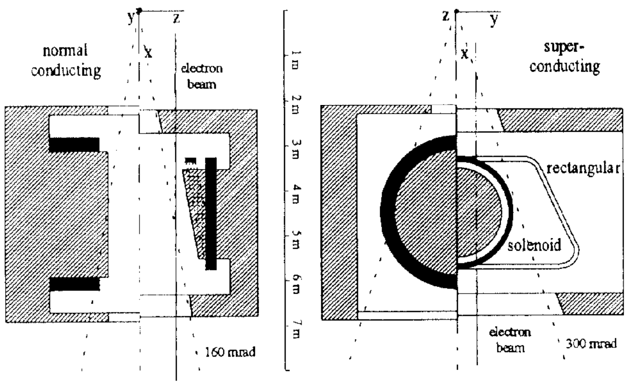

Figure 1: The geometry of the magnet

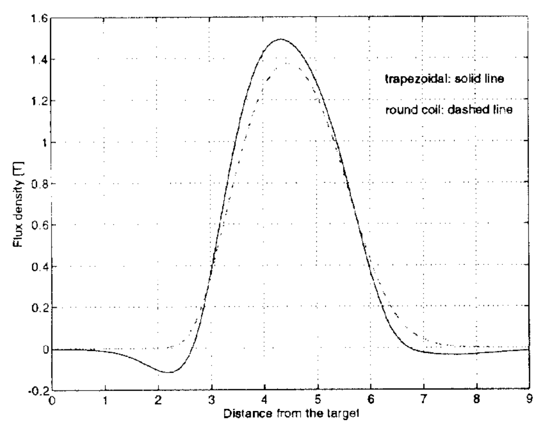

Figure 2: The field profile along the beam axis

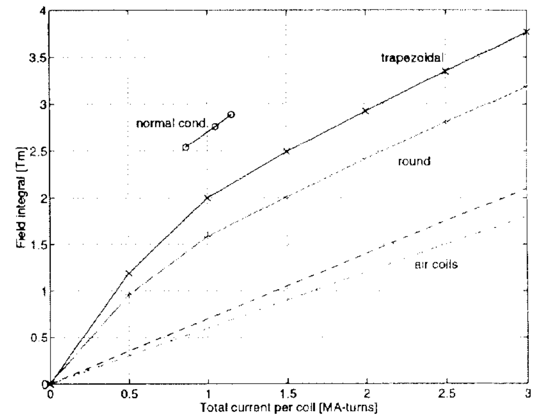

Figure 3: The load lines of the two magnets

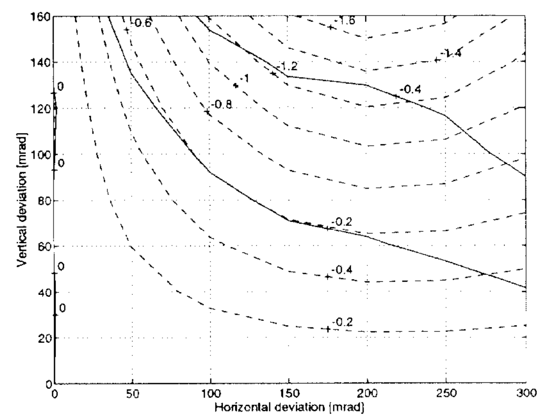

Figure 4: The field integral map (labels in Tm)

In Fig. 2 the field profile along the proton beam line is shown for the two considered coil geometries. For the round coil the stray field is practically zero (0.004 Tm before and 0.001 Tm after the magnet), whereas for the tilted trapezoidal coil the intensities are relatively large (0.110 Tm before and 0.068 Tm after). A much larger iron core would be needed in this case to limit the stray fields to some lower level.

The load lines of the magnets were computed for the selected geometries and are illustrated in Fig. 3. For comparison the air-coil cases are also shown. At the nominal excitation level the magnetization of the iron yoke gives roughly half of the field.

Fig. 4 shows the more crucial, horizontal magnetic field integral, $\int Bdl$, integrated from the interaction point through one quadrant of the magnet aperture as a function of the horizontal and vertical deviation angles. The lower left corner of the picture corresponds to the line integral along the proton beam axis. The better field quality of the trapezoidal coil (solid lines) compared to the round coil (dashed lines) can be seen clearly.

The three-dimensional numerical magnetic analysis of the magnet was done with the finite element program TOSCA by Vector Fields Ltd. [3]. Typical solution times for one case were around 140 minutes of CPU-time on a DEC 3000 AXP Alpha -computer.

3.2 *Design of the superconducting coil*

The cross-sections of each coil are identical, consisting of 286 turns of specially designed conductor. The coil and the main parameters of the coil and conductor are shown in Fig. 5. The coils are electrically connected in series.

For the cooling scheme of the coils, three different methods were considered:

- The helium bath cooling is the oldest method and therefore theoretically well understood. In addition a lot of engineering experience exists. The disadvantage is the low overall current density, around 30 MA/m^2, and the difficulties in the management of large forces.
- The cable-in-conduit conductor (CICC) is able to handle current densities of 100 MA/m^2 and, due to the complete separation of the force path from the coolant path, it is good for large coils of complicated geometry. The problems are that the cooling circuits (~200 m) are shorter than electrical conduit lengths and require

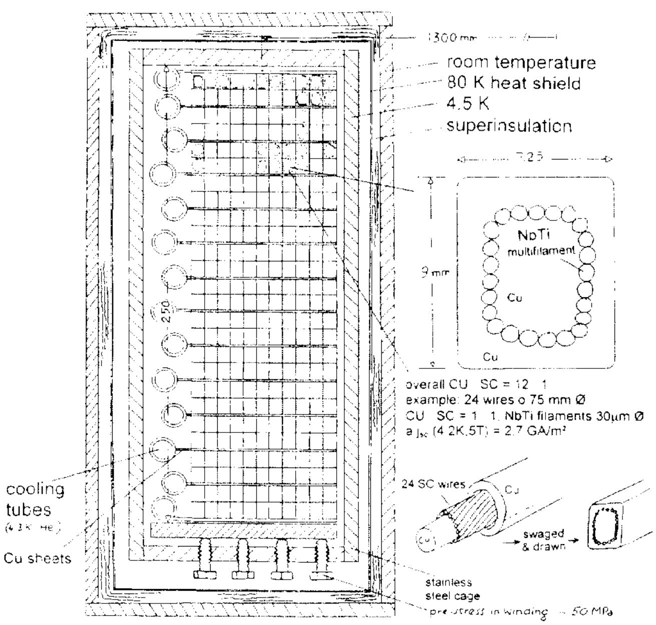

Figure 5: The cross-section of the coil (indirect cooling)

insulated helium connections, and that the engineering experience is not yet well established.

- The indirect cooling has high overall current densities (> 100 MA/m^2), the cryostat is very simple, the coolant path is separate from the current path and a reasonable amount of engineering experience exists [1],[2]. A disadvantage is that the temperature excursions within windings can be high, $\Delta T \approx 2$ K. Therefore more superconductor is needed, typically $j_{operating} < 0.5 \cdot j_c$ [4].

3.3 Forces

The attractive forces between current windings and neighboring iron are typically several MN/m. Usually the forces are reduced by placing iron on the opposite side and by other forces, attractive or repulsive, caused by other current carrying parts of the same magnet system.

In order to cancel the otherwise relatively complicated magnetic forces, the iron yoke of the magnet and the coils are designed to have two planes of symmetry. In transverse directions to the beam-line, the forces acting on the coil balance. For the present design with round coils, the net force at the working point is only 0.4 MN in the direction away from the target. For the trapezoidal case this force is about ten times larger.

The transmission of forces from 4 K to 80 K causes heat losses of $\dot{q} = (F/l)(k_{4-80}/\sigma_y)$ where k_{4-80} is the integrated heat conductivity, σ_y the yield strength, and l the length of the force support. For a stainless steel tension member of 0.2 m in length, $\dot{q}/F = 2.5$ W/MN, whereas for a 0.05 m long compression member of glassfibre-epoxy or bone the value is 0.5 W/MN [5].

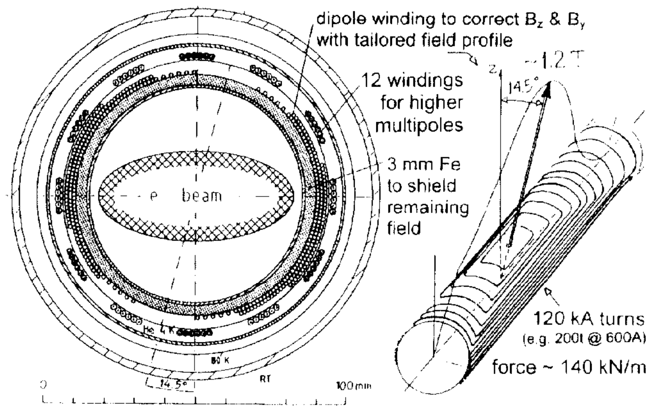

Figure 6: The structure of the shielding coils

4 SHIELDING OF THE BEAMS

The 3.3 Tm bends the 820 GeV proton beam by 1.2 mrad, which is compensated by 21 m long dipoles placed immediately outside the detector (displacement <5 mm).

Looking downstream, the e-beam passes through the magnet 0.8 m below and 0.45 m to the left of the proton beam as in Fig. 1. Following conditions should be met:

- a deflection < 0.1 mrad: $\int B_z dl \leq 0.01$ Tm
- polarization not disturbed: $\int B_y dl \leq 0.003$ Tm
- no superconducting cavities disturbing synchrotron radiation downstream: $\int |B| dl < 0.05$ Tm

The first two conditions could be satisfied by lumped correction dipoles, but such an arrangement would result in an unacceptable synchrotron radiation. Thus the last one is the most stringent condition.

A superconducting tube would make a perfect shield, but the state-of-art is still too experimental to expect a reliable solution without some R&D. The solution shown in Fig. 6 uses active superconducting windings to cancel the external magnetic field. An iron shield around the beam reduces the remaining field to an acceptable level. The field component parallel to the e-beam must also be compensated to keep the iron shield unsaturated.

5 REFERENCES

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