3 Magnet

The magnet consists of a superconducting solenoid and an iron yoke producing an almost uniform field parallel to the HERA beams. The field has only a few percent variation over the region of the tracking chambers. Within that region, 3600 mm in length and 1600 mm in diameter, the field has an average value 1.15 T.

3.1 The iron yoke

The iron yoke has the shape of an octagonal barrel with its axis parallel to the beam axis and to that of the solenoid which it encloses, plus flat end caps. In overall size it is similar to the ALEPH [17] and DELPHI [18] magnets at CERN. The requirements on uniformity of field are less stringent than for those experiments, which have chambers very sensitive to radial field components. Thus reentrant end caps are not needed for the H1 magnet and a much simpler opening mechanism is possible.

The yoke of the H1 magnet is separated into three parts, the northern and southern shells and the base structure (see Figure 4). The latter consists of the three lower faces of the octagonal barrel, and supports the superconducting coil. The northern and southern shells are mirror images of each other, symmetric about a vertical plane through the beam. Together they form all the rest of the octagonal barrel and the two end caps. Thus each shell is a rigid structure consisting of half of the western endcap and half of the eastern endcap, connected by 2.5 of the 8 faces of the octagonal barrel. Each of the three parts of the iron yoke moves independently on rails.

The iron of the octagonal barrel is made of 10 laminations each 75 mm thick, separated by air gaps of 25 mm accommodating a single layer of limited streamer tubes (LST), except for one air gap of 50 mm to accommodate a double layer of LSTs. The iron of the end caps is made up of 10 laminations each of 75 mm, separated by air gaps of 35 mm except for one air gap of 50 mm.

3.2 The superconducting coil

The main solenoid consists of four separate coaxial coils powered in series, symmetrically placed about the median vertical plane. The two coils nearest to the median plane ('central') are single layers, each of 201 turns, extending from 400 mm to 1420 mm from the median plane. The two coils farthest from the median plane ('peripheral') are double layers and have each 418 turns, extending from 1520 mm to 2580 mm from the median plane. All four of these windings are housed in one cryogenic envelope with an overall length 5750 mm, inner diameter 5180 mm, outer diameter 6080 mm. The superconductor, bonded into its aluminium substrate, was manufactured in industry [19]. The coils were fabricated from this conductor in modular form of length up to 1.5 m for both double and single layers on a custom built machine using the inside winding technique [20]. Liquid helium is supplied by the central plant at DESY. The parameters of this superconducting coil assembly are given in Table 2.

3.3 The magnetic field measurements

The general similarity in size and shape of the H1 magnet to those of the ALEPH and DELPHI magnets [17, 18] made it possible to use the same apparatus for the field measurements throughout a cylindrical volume of radius r = 1775 mm and length L = 5200 mm. The tracking chambers occupy only a smaller volume (r = 800 mm, L = 3600 mm, $-1125 < z < 2500$ mm) asymmetric to the median plane of the magnet (z = 1100 mm). The axial component B_z which needs to be known over the tracker volume with an accuracy of 0.3 % is shown in Figure 8 as function of radius and axial distance to the median plane. The average value over the volume is 1.15 T at the nominal magnet current of 5514 A, and the maximum departure from this value is 4.5% at the extreme backward end of the central tracker.

The longitudinal field integral $\int B_z dz$ for the H1 magnet was evaluated to be 8.32 T.m at the nominal current.

3.4 The forward muon toroid

The toroidal magnet for the forward muon detector consists of 8 solid iron modules built into two mobile half-toroids for access purposes. The inner radius of the toroid is 0.65 m, the outer radius 2.90 m, and the length between the flat ends 1.20 m. The weight is 250 tons.

There are 12 coils wound on the toroid, each consisting of 15 turns of water-cooled copper, carrying a current of 150 A. The copper windings are square in cross-section with side 11.5 mm, with a 8.5 mm diameter hole for water-cooling.

The magnetic field within the iron toroid has been measured by the change in flux, as the magnet is turned on or off, through loops of wire threaded through small holes in the iron. The field varies with radius, from 1.75 T at a radius of 0.65 m to 1.5 T at a radius of 2.90 m.

3.5 Compensating magnet

The compensating coil is located at the proton entrance side of the H1 magnet with its center at 4.4 m from the interaction point. Its purpose is to provide a longitudinal field integral $\int B_z dz$ equal and opposite to that of the main H1 magnet. This is required if longitudinal polarization of the electron beam is to be achieved. It also avoids horizontal-vertical coupling and minimises closed orbit shifts in HERA due to any misalignment of the H1 magnet [21]. Its downstream end extends into the endcap of the main magnet. This 1.8 m long superconducting coil was manufactured in industry [22] from NbTi cable embedded into a copper matrix insulated by glass fiber epoxy. The magnetic field is shielded by an iron yoke, with both iron and coil mounted inside a pressure vessel, which is cooled by liquid He from the main DESY transfer line. The relevant parameters are also given in Table 2. The field integral and the magnetic field axis have been determined by means of a rotatable Hall probe described in detail in ref. [23].

Solenoid parameters	**Main H1 magnet**	**Compensating magnet**
Superconductor		
Dimensions	26×4.5 mm^2	3.1×2.1 mm^2
Type	Rutherford cable on high purity Al (RRR 500) substrate	ABB-Zürich cable
Length (weight)	22.5 km (7.7 t)	4.5/4.5 km (0.49 t)
Winding geometry		
# of coils	2 ('central')/ 2 ('peripheral')	1
# of layers (turns)	1 (201)/2 (209)	14 (534)
# of turns: total	1238	7576
Inner radius	2750/2750 mm	320 mm
Outer radius	2800/2850 mm	429 mm
Cooling	support cylinder, forced flow	cryostat bath cooled
Vacuum chamber		
Inner/outer diameter	5200/6080 mm	238/870 mm
Length/thickness	5750/10 mm	2270/6 mm
Material	stainless steel	stainless steel
Radiation shield (50 K)		
Inner/outer diameter	5330/5950 mm	268/800 mm
Length/thickness/material	5370 mm/5 mm/Al	2135 mm/1.2 mm/Cu
Overall weight (rad. length)	74.5 t for coil (1.2 X_0)	6.8 t
Operational performance		
Power supply voltage	12 V	7 V
Current nominal (max.)	5517 (6000) A	870 (1000) A
Run up (down) time	80 (120) min	40 (40) min
Cooling time	168 h	168 h
He flow (4.5/50 K)	40/3 gs^{-1}	1.3/1.3 gs^{-1}
Cryogenic losses (4.5/50 K)	60/420 W	12.2/34.6 W
Total stored energy	120 MJ	1.87 MJ
Fast discharge time constant	60 s	40 ms
Fast discharge voltage	750 V	860 V
Field on axis (integral)	1.15 T (8.32 T.m)	4.83 T (8.74 T.m)

Table 2: Parameters of the superconducting magnets.