7.2 Concrete Stuffing for the LEP Magnets

Jean-Pierre Gourber

With LEP, CERN was confronted for the first time with the problem of producing a large number of magnets with a very low bending field. At the maximum design energy of 125 GeV, the field of the main dipole magnets was only 0.135 T, to be compared with the 1.5 T to 1.8 T of classical magnets for protons machines, but it had nevertheless to be very precise and uniform from unit to unit. CERN engineers faced up to the challenge of satisfying this unusual requirement by developing innovative solutions that would also result in substantial savings in cost.

The regular lattice periods in arcs were 79 m long with bending magnets made of six equal C-shaped dipole yokes (cores) between focusing quadrupoles. With the shorter cells at the arc ends, there were in total 3304 cores. These were excited by passing current through long bars of extruded hollow aluminium, insulated with glass-epoxy, and connected in series giving a single powering circuit (see Fig. 7.7). This solution was cheaper than traditional coils and minimized the space required for joints between magnets. The 5.75 m long cores were assembled in pairs at the surface with their common 12 m long excitation bars and lowered into the tunnel via a large elliptical shaft. The excitation bar interconnection was made *in situ* by TIG welding with special care to ensure continuity of the water cooling channel.

The cores were made as usual by stacking low carbon steel laminations. The transverse dimension of the gap was imposed by the dimensions of the vacuum chamber, the required 10^{-4} field homogeneity, and the mechanical stability of the flux return (backleg) during punching. Because of the low field, the laminations

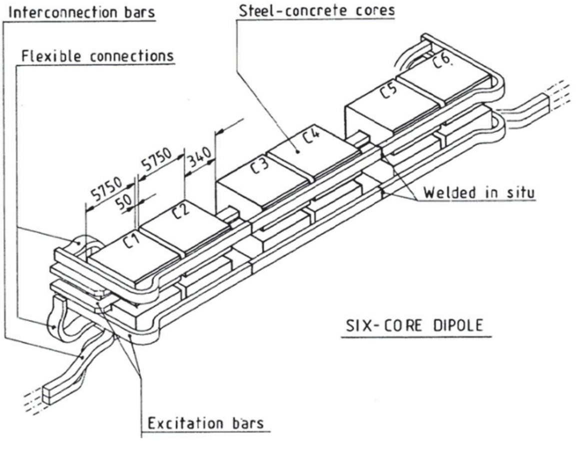

Fig. 7.7. Assembly of dipole magnet yokes at LEP.

could be spaced so that the field level in the flux return would reach the optimum value of 1.5 T at the maximum field, corresponding to 125 GeV. The spaces had to be filled with material cheaper than steel and the manufacturing process had to be economical. Somewhat surprisingly, concrete was proposed as the "stuffing" of choice of the voids between the iron laminations [29, 30]!

The 1.5 mm thick laminations were precision punched from decarburized steel sheet having good magnetic properties. The punching die also pressed suitable indentations which, by alternating the laminations, ensured the required optimum spacing of 4 mm in the stack (Fig. 7.8). The stack of laminations with its two 15 mm thick end plates was then placed in a mould and filled with a low shrinkage mortar. Four longitudinal rods anchored to the end plates were tensioned to provide compressive pre-stress of 0.5 MPa after de-moulding. This ensured that all points remained in compression during manipulation of the cores. The cores behaved like pre-stressed concrete beams; they were only half the weight of full steel cores and being very rigid they could be supported on three feet, making for easy alignment. The magnetic properties of these magnets were nevertheless very close to those of full steel magnets. The local variation of the field in the beam aperture due to the lamination spacing were less than 10^{-7}, and hence negligible.

The punching of the laminations by a single firm and the parallel fabrication of the cores by two civil engineering firms went smoothly and to the schedule of three years. On delivery to CERN, the *magnetic* geometry of the gap of each core was measured using a specially developed carriage. Complementing these survey measurements one core out of ten was equipped with a provisional set of excitation

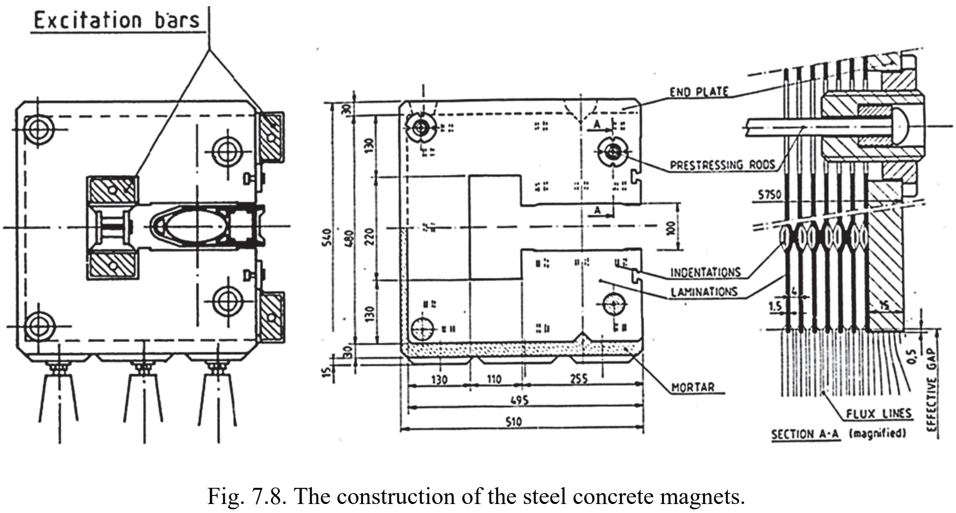

Fig. 7.8. The construction of the steel concrete magnets.

bars and its field measured. Results met specifications. However, when these measurements were repeated some months later there was a bad surprise: despite the use of a mortar carefully chosen for its low shrinkage, some residual shrinkage was occurring long after the cores were dry. The longitudinal effect of shrinkage had been anticipated in the design of the core, the supports and the excitation bars. But the shrinkage also had an unforeseen effect: it put the laminations into transverse compression. Such stress decreases the magnetic permeability of the steel, affecting the field in the gap [31]. Such a drift was unacceptable for an accurate energy calibration of LEP. The solution was to submit every core, one year after manufacture, to five cycles of a slight opening/closing of the gap, to provoke micro-fissures in the mortar and relieve the compression in the back leg. In addition, each core was equipped with a flux loop embedded in the lower pole. These loops, which were connected in series in the ring, were used to monitor the field in situ so that the influence of temperature variations, and eventual further ageing of the mortar, could be taken into account when determining beam energy.

7.3 Pumping LEP: Sticky Tape for Molecules

Cristoforo Benvenuti

Storage rings need a low residual gas pressure to minimize beam–gas interactions and keep the particles circulating for hours. For an electron storage ring, such as LEP, the problem is aggravated by the synchrotron radiation produced by the beams, which hits the vacuum chamber walls and desorbs a large amount of gas.

The small conductance of the vacuum chamber limits the flow of the gas molecules to the pumps, so reducing their pumping efficiency. At LEP, pumps with one metre spacing would have been needed to circumvent this problem. An elegant alternative solution adopted in similar previous projects consists in replacing the lumped pumps by a linear sputter-ion pump inserted in the dipole bending magnets. In this case pumping is ensured by ionizing the gas by a discharge ignited between two electrodes, and burying the ions in the cathode. The discharge is maintained at low pressure thanks to a high voltage and a high magnetic field applied to the pump. However, the field of the bending magnets at the LEP injection energy was too low to ignite the gas discharge in the pumps. Another solution had to be found. Finally, a getter strip [Box 7.3] inserted all along 23 km of the LEP chambers was adopted, as shown in Fig. 7.9 [32].