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Long Term Magnetic Performance of the Steel Concrete Dipole in LEP

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I. INTRODUCTION

The 3304 steel-concrete cores of the LEP bending magnets were built of regularly spaced steel laminations, the spaces being filled with cement mortar. The individual magnet cores are 5.75 m long and have a gap height of 100 mm. Their maximum bending field is 0.11 T. All magnet cores were individually measured before installation to determine the excitation characteristics and to calibrate the flux-loop mounted in the lower pole of each magnet [1]. The effects of compressive stresses in the steel laminations were studied on models [2] and the long term behaviour of the dipole cores has now been monitored during operation of the LEP machine over a period of four years. The requirements for stability and reproducibility of the magnetic field have increased in step with the development of the accelerator and its particle detectors. After the initial ageing in the LEP tunnel, the most important parameter was the temperature coefficient [3]. The temperatures of a number of magnet cores are therefore continuously monitored and corrections are applied to the indicated value of particle momentum as measured in the reference dipole. This dipole is made of a stack of standard dipole laminations without mortar filling and is connected in series with the bending magnets installed in the tunnel. It is provided with field measurement equipment such as a flip coil, a nuclear magnetic resonance probe (NMR) and a Hall effect magnetometer. This equipment forms part of the so called Field Display System [4]. The reference magnet is in turn calibrated periodically by a direct measurement of flux variations in the flux-loops and provided the original energy calibration of LEP [5]. This calibration was later verified and improved by injecting protons into LEP at 20 GeV and comparing the difference of rotation frequency with that of positrons on the same

orbit [6]. An absolute accuracy of 100 ppm was obtained. The energy calibration was further improved by measurement of resonant depolarization of transversely polarized beams at 45 GeV with a resulting accuracy of 10 ppm [7].

II. FIELD DISPLAY SYSTEM

A. Reference Magnet

The reference dipole provides information about magnet excitation characteristics including hysteresis and remanent field effects. The fact that the field in the LEP bending magnets is about ten times smaller than in most accelerators, makes these phenomena ten times more important than usual. Magnetic cycling of the dipole magnets is therefore very critical. The reference field depends on the temperature of the reference magnet since the field sensors do not cover the integral length of the magnet. Its temperature coefficient amounts to $-15 \text{ ppm}/^\circ\text{C}$, which is almost an order of magnitude below that of the steel-concrete dipoles. During normal operation the temperature of the reference magnet closely follows that of the average of the temperatures measured on the bending magnets in the tunnel.

B. Flip Coil

The flip coil is wound on a core of quartz glass in order to assure a low temperature coefficient of its equivalent surface. The temperature coefficient of the digital integrator varies from integrator to integrator but is always less than $5 \text{ ppm}/^\circ\text{C}$. The linearity and long term stability are both better than 50 ppm of maximum field. The main advantage of the flip coil measurement is that it is linear and covers the full range of measurements. On the other hand it suffers the disadvantage of being rather slow (several seconds per measurement). The standard deviation of a series of measurements at a given excitation current is better than 15 ppm of maximum field, but the reproducibility can be considerably increased by making the average of a few readings.

C. Nuclear Magnetic Resonance

This method has the advantage of being a primary standard for calibration and it is also a fast measurement. It suffers, however, the disadvantage of a limited measurement range as well as strict requirements for field homogeneity. Commercially available instruments, like the one employed, are difficult to use below fields of about 0.1 T as readings are not always reliable. The probe in use has a range of 0.045 T to 0.13 T and a standard deviation of a series of

measurements at a given excitation current of about 10 ppm was observed. Special pole pieces have been mounted around the NMR probe in order to enhance the flux density. This improved the field strength by a factor of two and thus the measured resonance signal.

D. Hall Effect Gaussmeter

This instrument has the advantage of providing an instant reading, covering the full field range, but it gives a less accurate result. It is fine for a fast check of the magnet status, but is not to be employed in cases where high precision is required.

III. FLUX-LOOP

A. Measurement Principle

Two kapton insulated copper wires forming a one turn induction coil, linking the useful magnetic flux, are embedded in each lower pole of all bending magnets.

Individual flux-loops are connected in series forming eight circuits around the LEP ring. Each of these circuits is connected to a digital electronic integrator, which measures flux variations very precisely over an octant length of 3.3 km. The measurement principle is illustrated in Fig. 1 and described in detail in [5]. Polarity reversal permits a measurement of the remanent field which is of particular importance in these low-field dipoles. This measurement equipment forms the so called Flux-Loop System. The integrators used for the flux-loops are identical to the one used with the flip coil of the Field Display, so temperature effects of these can be neglected.

B. Temperature Measurements

The temperature effect of the steel concrete dipoles was observed in the LEP tunnel and also studied in our magnet measurement laboratory. The temperature coefficient was about 120 ppm/°C at 45 GeV. So the critical parameter for the flux-loop measurement is clearly the magnet temperature. Platinum resistor thermometers were mounted on a number of magnets located through the length of the LEP tunnel.

Fig. 1. Principle of flux-loop measurement

Fig. 2. Dipole temperature distribution

Fig. 2 shows a typical magnet temperature distribution measured around the LEP tunnel. It can be seen that the magnet temperatures are higher near pits 6 and 2, where the LEP radio frequency systems are located and the lowest in the tunnel between point 3 and 4. This temperature pattern has been observed for all flux-loop measurements at different average temperatures. Fluctuations of the individual magnet temperatures with respect to this pattern was less than 0.3 °C rms.

C. Flux-loop Calibrations

A total of 63 flux-loop measurements were carried out during the 4 year period of LEP operation. A measurement consisted usually of four complete measurement cycles with a typical dispersion of about 20 ppm. The result is expressed as the difference between the value measured by the flux-loop and the related field display reading. Fig. 3 shows these values for a 45 GeV field setting versus the date of measurement. It is seen that a pronounced ageing process took place over the first two years of operation. Temperature

Fig. 3. Summary of flux-loop measurements

corrections were introduced from June 1991 and improved from May 1992. For reasons of economy LEP is not in operation during the winter months. The behaviour of the magnet during the seasons 1991 and 1992 looks somewhat periodic. This could be caused by humidity effects which are now being studied in our magnet measurement laboratory. The latest variations of measurement results obtained this year have been confirmed by those of resonant depolarization.

IV. CONCLUDING REMARKS

The precise value of the particle momentum is of utmost importance for the physics experiments being carried out in LEP. It has been proved that a precise value of the particle energy can be obtained from magnetic measurements in the reference magnet provided that periodical flux-loop measurements are performed combined with the resonant depolarization calibrations. Continuous monitoring of the dipole temperatures provides the necessary field corrections.

An illustration of the field stability obtained during a 24 hour period was shown in a dedicated experiment where the effects of the terrestrial tides on the LEP circumference was measured [8].

This work also illustrates the importance of systematic magnetic measurements of accelerator magnets.

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REFERENCES

- [1] J. Billan, J.P. Gourber, G. Guignard, K.N. Henrichsen, J.M. Mangain, R. Wolf, "Magnetic performance of the LEP bending magnets", 1989 Particle Accelerator Conference, Chicago, USA (1989) 1148-1150.
- [2] J. Billan, J.P. Gourber, K.N. Henrichsen, H. Laeger, L. Resegotti, "Influence of mortar-induced stresses on the magnetic characteristics of the LEP dipole cores", IEEE Trans. on Magnetics, vol. 24, no.2 (MT-10) (1988) 843-846.
- [3] J. Gascon, R. Giachino, V. Hatton, K.N. Henrichsen, J. Panman, "The temperature dependence of the energy calibration of LEP beams by flux-loop measurements", LEP Performance Note 74, (1991), unpublished.
- [4] J. Billan, J.P. Gourber, K.N. Henrichsen, L. Walckiers, "Field display system for the forecast of beam momentum and betatron frequencies in LEP", Particle Accelerators, 29 (1990) 215-220.
- [5] J. Billan, J.P. Gourber, K.N. Henrichsen, "Determination of the particle momentum in LEP from precise magnet measurements", 1991 Particle Accelerator Conference, San Francisco, USA (May 1991) 2122-2124.
- [6] R. Bailey et al., "LEP Energy Calibration", 2nd European Particle Accelerator Conference, Nice, France (June 1990) 1765-1767.
- [7] L. Arnaudon et al., "Measurement of the mass of the Z boson and the energy calibration of LEP", subm. to Phys. Lett. B.
- [8] L. Arnaudon et al., "Effects of tidal forces on the beam energy in LEP", 1993 Particle Accelerator Conference, Washington D.C., USA (May 1993).