DETERMINATION OF THE PARTICLE MOMENTUM IN LEP FROM PRECISE MAGNET MEASUREMENTS

J. Billan, J. P. Gourber and K. N. Henrichsen
CERN, CH-1211 Geneva 23, Switzerland

Abstract

The absolute beam energy of LEP is obtained by measuring the magnetic field in a reference dipole connected in series with the bending magnets of the machine. Periodic calibrations are carried out by measuring flux variations in a one-turn induction coil embedded in the lower pole of all bending magnets. The measurement equipment is described and the results of periodic calibrations are reported.

I. INTRODUCTION

The precise value of the particle momentum is of utmost importance for the physics experiments being carried out in LEP. An accurate measurement of beam momentum is obtained by measuring the magnetic field in a reference dipole connected in series with the bending magnets of the machine. This reference magnet is similar to the dipoles installed in the machine, but was built without the mortar filling. It is calibrated periodically by a direct measurement of flux variations in the so-called flux-loop which is a one turn induction coil embedded in the lower pole of all bending magnets installed in the machine. The absolute value measured at beam injection energy was later confirmed by the measurement of the revolution frequency of injected protons.

II. THE FLUX-LOOP

A. The flux-loop coil

Two polyimide insulated copper wires forming a one-turn induction coil, linking the useful magnetic flux, were embedded in each lower pole of all bending magnets. The presence of a thin mortar layer on the pole faces of the dipole cores, in the proximity of the shims, made it possible to grind with high precision two small grooves in the lower poles into which the wires were placed [1].

B. Calibration of individual flux-loops

The "magnetic surface" of each of the 3280 flux-loops was determined, during the systematic magnetic measurements of the dipoles, by varying the magnetic field and comparing the values of flux induced simultaneously in the individual flux-loops and in the search coil used for the determination of the field integral of the dipoles [2]. Periodic measurements on a sample of cores have shown an ageing of the magnetic surface of less than 50 ppm per year. This phenomenon is due to the residual shrinkage of the magnet length.

III. MEASUREMENT EQUIPMENT

A. The Field Display

A reference dipole is connected in series with the LEP main dipole magnets. This reference dipole was made from a stack of standard dipole laminations. In order to ensure the best possible magnetic stability, it was not filled with mortar, but was mounted in a special supporting frame. Measurements of the magnetic field strength are carried out with a flip coil mounted in the magnet gap along the position of the central orbit. The magnetic flux variation is measured by a digital integrator. The resolution of the measurement is about 20 ppm and a corresponding reproducibility was confirmed. A more detailed description of the Field Display is given in [3].

B. The flux-loop integrators

The measurement equipment consists of eight digital integrators placed in the even underground areas of the machine, and each measuring a series of flux-loops over an octant length of about 3.3 km. The necessary controls are provided through the LEP control system, which also activates the dipole power converters and the measurement apparatus related to the reference magnet.

IV. ENERGY CALIBRATION

A. Measurement procedure

Figure 1 illustrates the principle of the beam energy calibration. After several magnetization cycles between 300 A and 2900 A, sequential measurements with the Field Display at constant field and the induced flux during ramping of the dipole field are performed. The measurement sequence includes a change of polarity in order to determine the remanent field which is of particular importance in these low-field dipoles. The positive and negative values of the remanent field are not symmetrical, but the ratio of these values is directly measured in the reference dipole and used to determine the positive value in the bending magnets from the

0-7803-0135-8/91$01.00 ©IEEE

measured difference in those. It should be noted that, although the measured flux changes are relatively big, the integration periods during ramping are also long. It is therefore necessary to correct the measurements for the drift of the integrators. This drift is measured during the Field Display measurement, which takes place at constant field. Furthermore, the offset of all integrators is measured and reset before each measurement cycle. The duration of a complete calibration cycle is about 30 minutes.

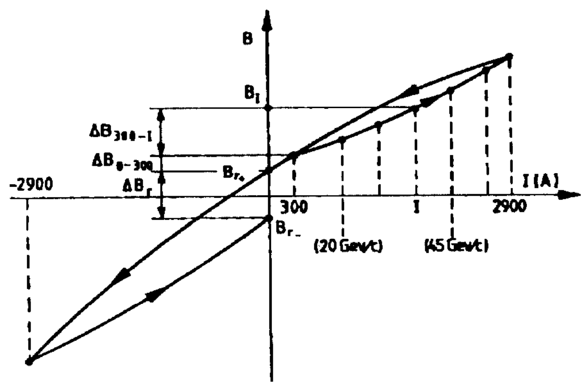

Fig. 1 Principle of beam energy calibration

B. Corrections for field not seen by the flux-loop

The flux-loop measurement does not include end- and junction-effects. These corrections were based on detailed measurements on a sample of magnet cores and represent approximately 1.6 % of the physical length of the dipole. An additional correction was necessary to compensate for the influence of the thin nickel layer which was needed for the cladding of the lead-shielding against synchrotron radiation. The application of compensating shims mounted at the end of the dipole cores reduced this effect by a factor of ten to a value less than 100 ppm.

C. Measurement results

Periodic flux-loop calibrations have taken place since October 1989 and have provided the necessary information about the value of beam momentum. Figure 2 shows the results of the absolute calibrations at 45 GeV. Calibration results for the difference between 20 GeV and 45 GeV are shown in fig. 3. The absolute value measured at beam injection energy, 20 GeV, was later confirmed by the measurement of the revolution frequency of injected protons [4]. An agreement to within 0.02 % was observed. The determination of beam momentum at collision energies, however, depends entirely on the flux-loop measurement. Monthly energy calibrations are foreseen in the future in view of their importance for the LEP physics experiments. At a later stage, the flux-loop calibration will permit the unambiguous detection of the depolarization resonances distant by 440 MeV, and the improvement of the accuracy of the beam energy calibration to within 50 ppm [5].

A reproducibility of 0.01 % of full scale over the whole measurement range was obtained during the flux-loop calibrations. An absolute accuracy of 0.03 % was reached by combining the flux-loop measurement with a measurement of revolution frequency of protons at injection energy.

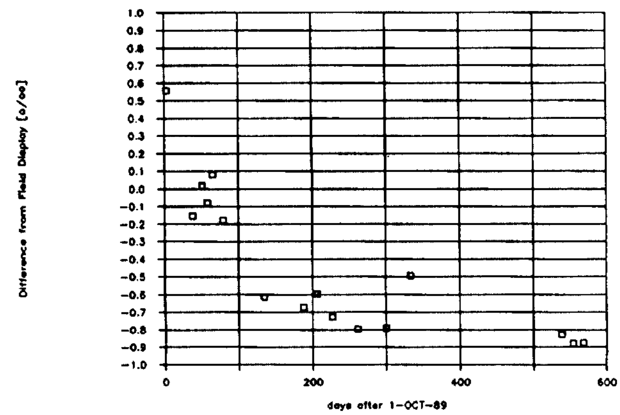

Fig. 2 Periodic calibrations of absolute energy

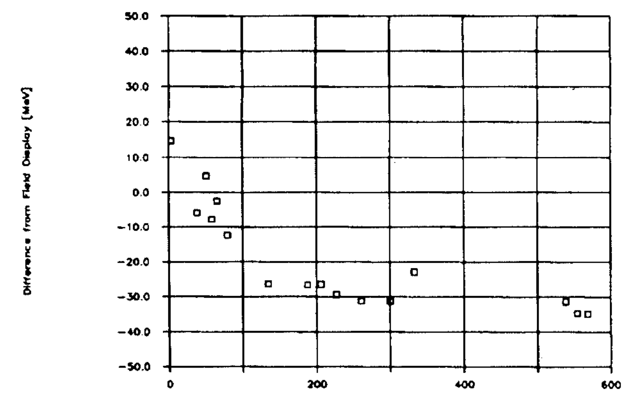

Fig. 3 Differential calibration between 20 GeV and 45 GeV

V. Concluding Remarks

This work illustrates the important value of systematic magnetic measurements of accelerator magnets. The measurement results did not only provide a precise knowledge of the beam energy, but also permitted the sorting and subsequent positioning of magnets in the machine according to magnetic properties in a cost-efficient way.

VI. Acknowledgments

The authors are grateful to P. Galbraith for his design and construction of the digital electronic integrators and for their connections to the LEP control system. Thanks are also due to K. Dahlerup-Petersen for the necessary modifications of the power converters for the LEP dipoles. Last, but not least, we want to thank P. Defert and R. Keyser for the programming of the control computers, meeting the requirements for this rather complex task.

VII. References

[1] 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", 10th Int. Conf. on Magnet Technology, Boston, USA, (March 1989).

[2] J. Billan, J.P. Gourber, G. Guignard, K.N. Henrichsen, J.M. Maugain, R. Wolf, "Magnetic Performance of the LEP Bending Magnets", 1989 Particle Accelerator Conference, Chicago, USA, (March 1989).

[3] J. Billan, J.P. Gourber, K.N. Henrichsen, L. Walckiers, "Field Display System for the Forecast of Beam Momentum and Betatron Frequencies in LEP", XIV Int. Conf on High Energy Accel., Tsukuba, Japan, (August 1989).

[4] R. Bailey et al., "LEP Energy Calibration", 2nd European Particle Accelerator Conference, Nice, France, (June 1990).

[5] L. Knudsen et al., "First Evidence of Transverse Polarization in LEP", Symposium on High Energy Spin Physics, Bonn, Germany, (September 1990).