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by

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FIELD DISPLAY SYSTEM FOR THE FORECAST OF BEAM MOMENTUM AND BETATRON FREQUENCIES IN LEP

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Abstract. The forecast of particle momentum and betatron frequencies during LEP operation is based on field measurements in a set of reference magnets connected in series with the main ring magnet strings. The measurements are performed both at steady conditions and during ramping of the magnet excitation currents. The influence of eddy currents on the magnetic field is evaluated by performing the dynamic measurements inside the respective types of vacuum chamber.
The measurement in the reference dipole provides information about the field integral in the bending magnets, and thus gives the value of particle momentum at central orbit. Two reference quadrupoles provide the information about the focusing parameters.
The reference dipole is calibrated periodically by a direct measurement of flux variations in a loop mounted in the lower poles of all bending magnets installed in the tunnel. Polarity reversal permits a measurement of the remanent field which is of particular importance in these low-field dipoles. Beam momentum will thus be determined to an accuracy of better than 0.05 %.

INTRODUCTION

The large electron-positron beam collider (LEP) which has recently started operation at CERN is a separated function machine[1]. The main bending magnets equipped with steel-concrete cores and excitation bars are all connected in series around the ring. In the two injection regions, the main bending magnets have been replaced by shorter double-field magnets which are excited in a separate circuit. The quadrupoles of the arcs are also connected in two circuits (horizontally focusing and vertically focusing, respectively). In the long straight sections around the interaction points, the quadrupoles are powered independently.

The operation of LEP requires a precise knowledge of beam momentum and focusing strength both in static (injection - flat-top) and dynamic (particle acceleration) conditions. Furthermore, the experimentalists need as precise a definition as possible of the beam momentum. Each of the three major strings of magnets have, therefore, been provided with a reference magnet which is located in a surface building and is equipped with a system to monitor the field. The fields are measured inside a representative length of vacuum chamber, to include the effects of residual magnetism and eddy currents.

The field and gradient measurements performed in the reference magnets are correlated with those which have been performed on each individual magnet, so as to obtain the field and focusing strengths integrated over the ring.

The steel-concrete cores of the bending magnets are subject to ageing[2] which slightly reduces the field and thus affects the ratio between the actual field strength in the ring and the field measured in the reference magnet. To alleviate this effect, the bending magnets in the ring are equipped with a one-turn flux loop embedded in the lower poles. This flux-loop system makes it possible to calibrate periodically the ratio of the actual bending strength in the ring with respect to the field measured in the reference magnet.

DIPOLE FIELD DISPLAY SYSTEM

The reference dipole is made of 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 frame. The magnetic measurements are performed both at constant field conditions and during ramping of the magnet excitation currents using two different search-coil systems.

Measurements of the static magnetic field are carried out with a flip coil mounted in the magnet gap along the position of central orbit. The coil is wound on a 1 m long rectangular core made of Pyrex® glass, ensuring good thermal stability of the coil surface. The coil is rotated 180° in each direction by an electric motor. The flux is measured by a digital integrator triggered at the beginning and at the end of each movement.

The dynamic magnetic field applied during particle acceleration is measured using a fixed coil. In view of the relatively long ramping periods, this coil is wound on a larger core giving a magnetic surface of the order of 20 m^2. The flux is measured by a digital integrator which is triggered synchronously with the quadrupole integrators at a rate of ten measurements per second. The start of the measurements is initiated through the standard timing system of LEP by the same event that starts the ramping of the power converters.

A faster but less accurate measurement is provided by a Hall probe which is also mounted at the central orbit position. This instrument has a sensitivity of 1 μT. An NMR-probe is foreseen for the periodic global verification of the measurement apparatus.

The measurement in the reference dipole provides information about the field integral in the main bending magnets and, after the addition of the 1.5 % contribution of the double-field magnets, the value of particle momentum at central orbit. The resolution of th the static and the dynamic measurement is about 20 ppm and a corresponding reproducibility of the measurements has been confirmed.

The reference dipole system is calibrated periodically by a direct measurement of flux variation in the flux-loops mounted in the lower poles of the bending magnets. These loops are connected in series throughout each of the octants of LEP. The flux variation is measured by eight digital integrators placed in the even underground areas of the machine and which in turn are connected to the LEP control system. Polarity reversal permits a measurement of the remanent field which is of particular importance in these low-field dipoles. This makes it possible to determine the beam momentum to an accuracy of better than 0.05 %. The calibration procedure is described in detail in Ref. 2.

QUADRUPOLE FIELD DISPLAY SYSTEM

Each reference quadrupole is also equipped with a rotating and a static coil. The rotating coil is also wound on Pyrex® cores. The bearings at each end are held in a frame on which is wound the fixed coil. Both coils are 1 m long and have quadrupolar symmetry in order to be insensitive to positioning with respect to the magnetic axis (Fig. 1): a 5 mm off-axis displacement of the coils gives no change in the gradient reading. An angular encoder is located as near as possible to the end of the coil and allows to take eight equidistant integrated voltage readings per turn so that no adjustment of its zero is needed. The connections between the rotating coil and the integrator are made via slip-ring contacts to simplify the motor control and mechanics.

All LEP quadrupoles were measured by the harmonic method[3]; an overall calibration of these integrated gradient measurements leading to a correction of $5\ 10^{-4}$ was performed by the moving wire method. This latter method integrates the flux crossed by a multistrand wire stretched parallel to the quadrupole axis and displaced in the vertical plane by distances given by slip gauges, the return wire remaining fixed. The fluxes, F1 and F2, measured during two equal and adjacent displacements, d, give directly the quadrupole strength integrated over the coil length:

$$G \times L_{eff} = 2 \times (F1 - F2) / d^2 .$$

The rotating coils of the quadrupole field display system were also calibrated with the moving wire. Furthermore, the series measurements were corrected to take into account the residual magnetism of the vacuum chamber.

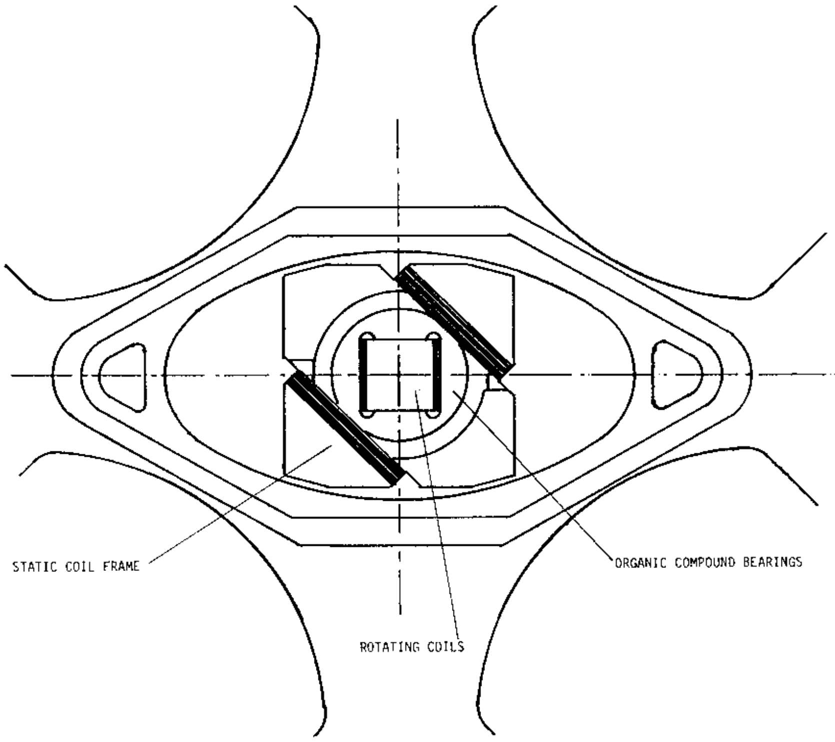

FIGURE 1 Geometry of field display quadrupole

These various measurements allow to estimate to 5 10^{-4} the absolute accuracy on the focusing strengths which are given by the quadrupole field display system and which represent about 60 % of the total focusing strengths of LEP. The reproducibility obtained is 1 10^{-4} r.m.s. at LEP injection and improves at higher energies.

THE USE OF THE FIELD DISPLAY SYSTEM

During operation of the LEP machine, the reproducibility of the magnetic field of the main dipoles and quadrupoles is monitored by static field measurements in the reference magnets. This proved very useful, in particular for the dipoles which show relatively large hysteresis effects. The dipole measurement also indicates the precise setting of energy for LEP.

The synchronization of the magnetic field is of vital importance during particle acceleration. The dynamic measurements permit to monitor variations of the focusing strengths, i.e. the ratios of the quadrupole fields to the dipole field. Simultaneous measurements in the three reference magnets are performed with the sampling period of 100 ms during the increase of the magnetic fields. At the end of each measurement, the tables of results are transmitted through the LEP control system for analysis at a console in the Control Room. The flux measurement is related directly to the static field measurements performed before and after the field ramp. This procedure eliminates the effects of integrator drift and the need for any periodic coil and integrator calibrations.

An example illustrating the resolution and reproducibility of this measurement is shown in Fig. 2. The relative variation of the focusing strength in one string of quadrupoles is given as a function of beam energy.

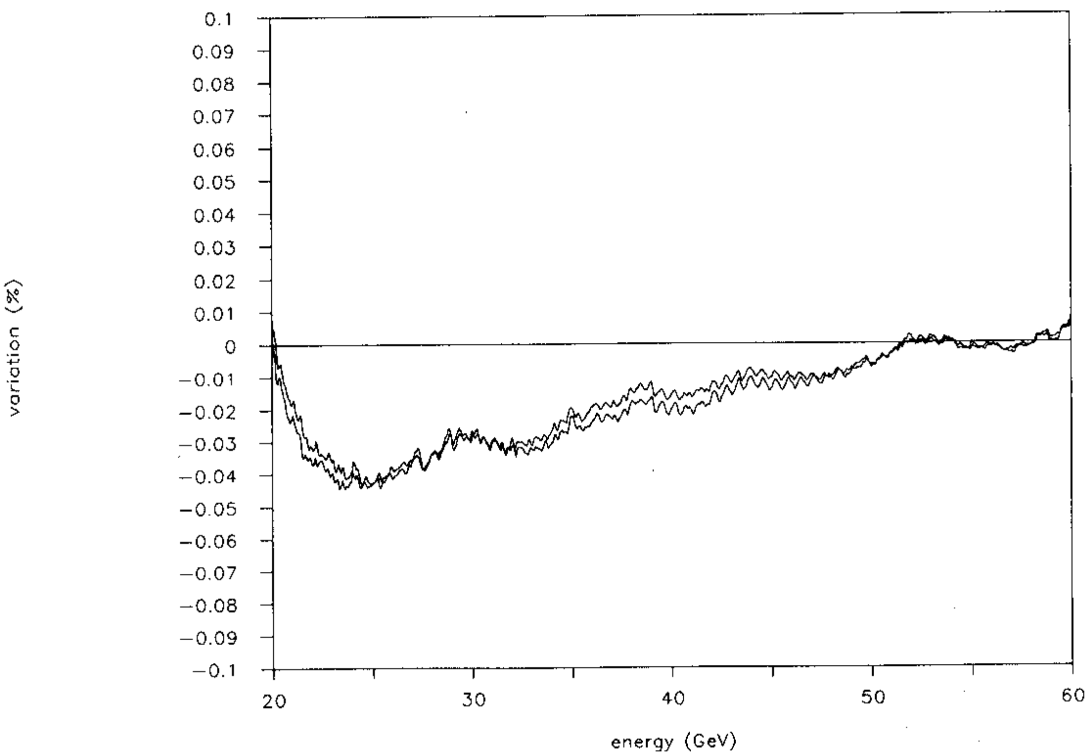

FIGURE 2 Reproducibility of focusing strength versus energy

The time constant for the magnet circuits and for the eddy currents in the vacuum chambers are very different for the dipole magnets and the quadrupole magnets. The field display system has, therefore, proved very useful, not only for the development of the tables of excitation currents as a function of time, but also for the final adjustments of the control loops of the power converters. A possible time lag between the magnetic fields seen by the beam can be easily detected and corrected, as is shown in Fig. 3.

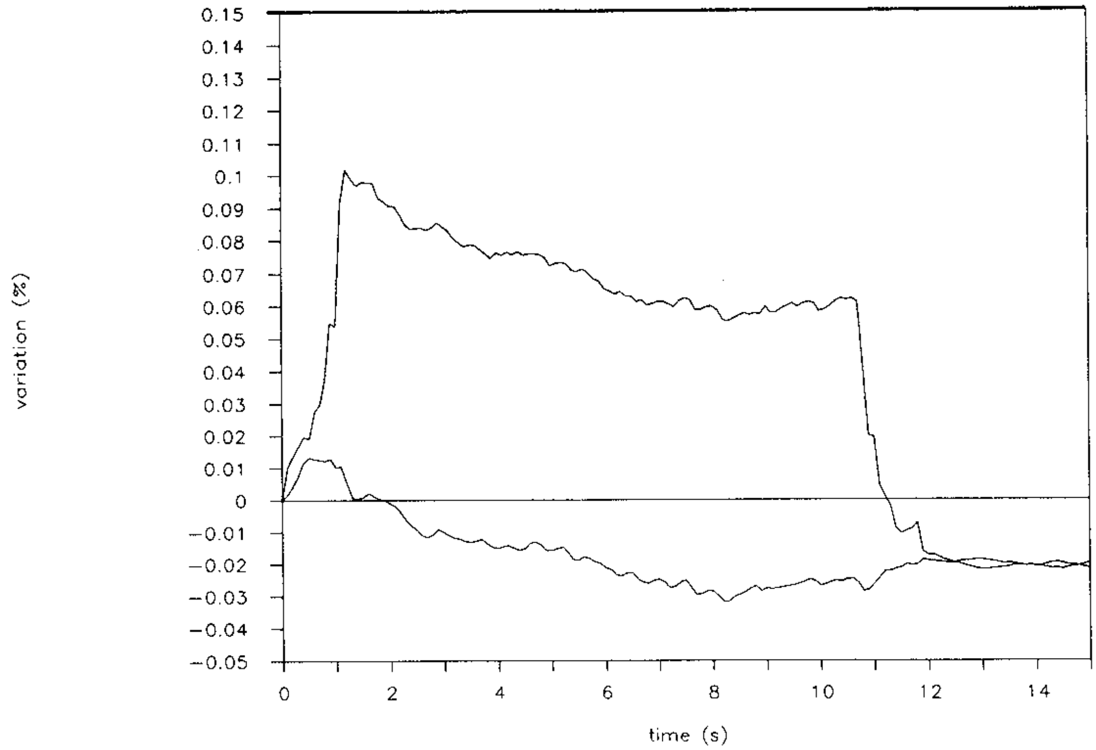

FIGURE 3 Focusing strength versus time before and after correction of the time lag

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