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MODEL OF DIPOLE FIELD VARIATIONS IN THE LEP BENDING MAGNETS

E. Bravin, B. Dehning, A. Drees, G. Mugnai

Abstract

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A LEP dipole test bench was set up for systematic investigations. Field variations were monitored with NMR probes while the cooling water temperature of both coil and vacuum chamber was kept under control. The results lead to a parametrisation of the magnetic field variation as a function of the vacuum chamber current and temperature.

1 INTRODUCTION

The LEP collider contains 3280 dipole magnets. Each core is 5.75 meters long and 4.6 tons in weight. Due to the weakness of the required magnetic field –the maximum field is 1100 Gauss corresponding to 100 GeV– a new technique was adopted for their construction[1, 2]. A series of 1.5 mm thick low-carbon steel lamination separated by a 4 mm gap are stacked together. The mechanical stability of the construction is granted by the cement mortar which fills the space in between the laminations (see Fig. 1). This particular design for the magnets allowed large economic advantages in the construction of LEP.

Two NMR probes in two dipoles were used to determine the bending field of LEP tunnel magnets. A systematic field rise of the order of 10 MeV was observed during each fill[1]. This rise was accompanied by a noise of the same order of magnitude and frequency of some fraction of a Hertz. The noise then disappeared between midnight and four hours in the morning.

After some investigation this phenomena from railways was traced to be induced by leakage currents. The DC current which powers the SNCF train line Geneva-Lyon flows over the railways back to the generator. Due to the finite resistivity of the rails a part of this current flows in the ground and finds a good conductor in the LEP vacuum chamber [3, 4].

In order to understand this effect a model for the time evolution of the LEP bending magnet field was required.

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[1] A physics fill is the period between the injection and the dump of the beam, it last about 10 hours

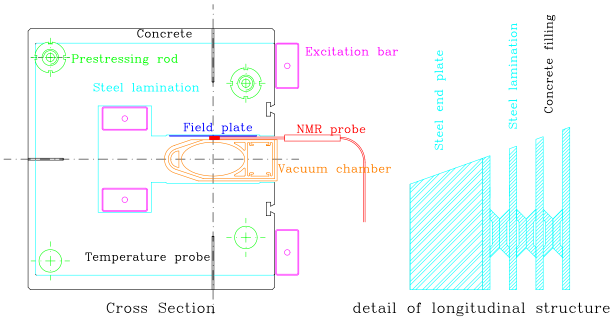

Figure 1: Cross section of the instrumented LEP dipole. The iron-concrete structure is shown on the right side.

The knowledge of the temperature coefficient was needed in order to decompose the field variations in a temperature part and a train current part.

A new test bench with the primary objective of measuring the temperature coefficient of the LEP dipoles and the secondary objective of understanding the train current effect was proposed.

2 THE TEST BENCH

The installation consisted of an instrumented spare LEP dipole. Particular effort was taken to reproduce as closely as possible the same conditions as in LEP.

Thirty two temperature sensors were used to monitor the temperature evolution of the core, the coils and the vacuum chamber (see Fig. 1). Two NMR probes permitted the monitoring of the magnetic field with an accuracy better than 10^{-5} while a precision instrument (DCCT) monitored the magnet current. Three position sensitive potentiometers were used to measure the yoke gap height variations.

Iron field plates were glued on the upper magnetic pole of the yoke at the location of the NMR probes to provide the field uniformity required by the instruments (see Fig. 1).

Two different power supplies were available, one delivering the excitation current of up to 6000 A and the other generating the simulated train current over the vacuum chamber of up to ± 10 A.

A regulated cooling system was used to set the temperature of the vacuum chamber and of the excitation coils. The core has a time constant of $\sim$5 hours.

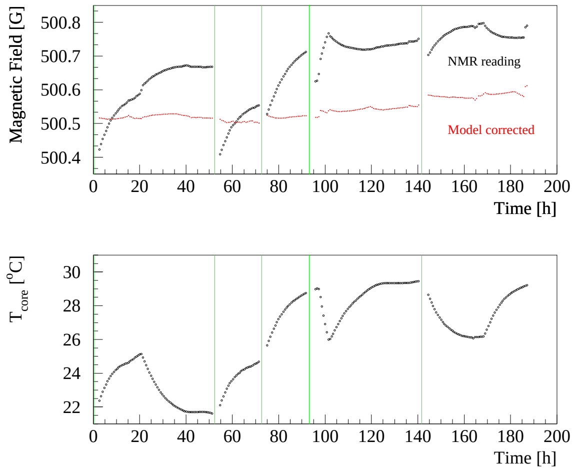

Figure 2: Temperature experiment performed on the test bench. The two lines in the top plot represent the raw and the temperature model corrected magnetic field as function of time. The lower plot shows the mean temperature of the magnet yoke. Vertical bars marks the start of each period.

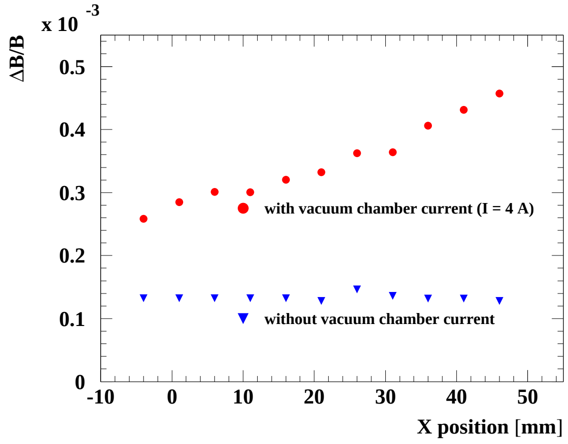

Figure 3: The magnetic field profiles in the horizontal plane transverse to the beam (x direction). Dots: Field perturbation due to train current. Triangle: Remaining field after the train current excitation.

The dipole magnet excitation was 500 G.

3 THE TEMPERATURE BEHAVIOUR OF THE LEP DIPOLES

The temperature variations produce gap height variations, magnetic pole area changes and stresses in the structure.

Gap variations are caused by the global expansion arising from mean temperature variations of the magnets and by a temperature gradient around the internal excitation bars. The gradient arises from the different temperatures between core and coil. These gradients tend to open or close the C shape magnet. The magnetic pole area changes due to the thermal expansion of the materials. Stresses arise in the interface region between the steel laminations and the concrete. The whole iron lamination is influenced by the stresses, which result in magnetic permeability variations. Temperature changes of the core can therefore modify the stress status and influence the magnetic field. How the stresses depend on temperature variations is not understood.

The result of a particular experiment used to determine the thermal model for the LEP dipoles are shown in Fig 2. This experiment which lasted over 8 days consists of 5 periods. Each starts with a degauss cycle in which the excitation current is varied between 300 and 2900 A several times to restore the magnetic initial conditions. The current is then set to the value used to run LEP at the Z^0 peak energy of 2000 A. In the following time (varying from 10 to 40 h) the temperature of the cooling water is changed in a controlled way. The first period shows a monotonic rise of the field for both increasing and decreasing core temperature. The second and the third are partial repetitions. The forth and the fifth show both: increase and decrease of the magnetic field by applying the reverse temperature variation pattern with respect to the first. In case of exact the same sequence is applied to the magnet a good reproducibility of the behaviour is observed. This doesn't correspond to easy predictions if the sequence is changed. Therefore two non linear component had to be introduced in the model: the *maximum* and the *minimum* temperatures achieved by the core since the beginning of the period (i.e. beginning of fill). The difference between model and measurements show largely reduced variations (see Fig 2). The model with its parameter values is published in [5].

4 EFFECT OF TRAIN CURRENTS

As already mentioned leakage currents from the railway system flow over the vacuum chamber of LEP. The amplitude is of the order of ±5 A which corresponds to roughly ±100 mG or ±10 MeV.

The field produced by a current flowing over the vacuum chamber has a dipolar and a quadrupolar component. The field has a minimum at the inner edge of the chamber and reaches its maximum at the outside edge of the magnetic yoke (see Fig. 3).

Due to the hysteresis effect of iron the magnetic field is not simply proportional to the current flow. There is a field rise produced by the change of the working point as shown in Fig. 4.

When the magnetic field is modulated around the working point a secondary hysteresis loop is approached. This secondary loop has the upper tip on the primary cycle while the lower tip sits at a higher field value compared to the primary cycle. The net result is an increase of the working point field (when the chamber current vanishes again). In our case the modulation does not consist of smooth current changes but of either polarities spikes. A positive spike

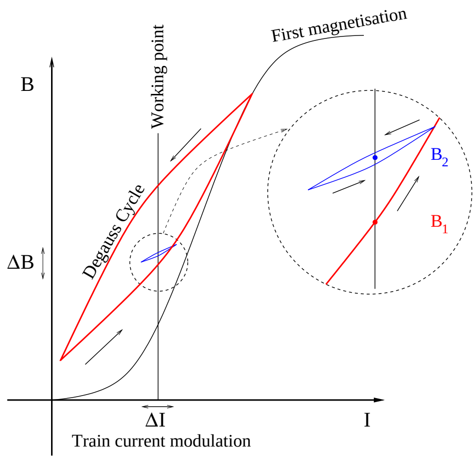

Figure 4: The hysteresis effect of the current flowing over the vacuum chamber.

leads to a "jump" of the magnetic field while a negative one does not produce any noticeable effect (here the upper tip of the secondary cycle coincide with the working point).

If a positive spike of a certain amplitude took place at a certain time, subsequent smaller spikes would not produce any permanent effect. However a new spike of larger amplitude would lead to a further increase of the magnetic field.

The reproducibility of the effect of train currents was verified in a dedicated experiment. The current recorded in the LEP tunnel was replayed to the vacuum chamber of the test bench magnet (see Fig. 5 lower plot). The field evolution obtained in this simulation could be compared with the NMR data recorded in a LEP tunnel magnet (see Fig. 5 upper and middle plot). The first large current increase at 5:20 causes a remanent field increase. The following lower current variations did not result in a permanent increase.

A general model able to describe how the temperature and the train current effects combined together has been developed using the results of the test bench. Both effects act on the iron magnetisation and cannot be linearly superimposed. A more detailed description of the combination of these effects are published in [5].

5 CONCLUSIONS

The test bench measurements described allowed the development of a model of the magnet field variations, taking into account the yoke and the coil cooling water temperature. The parametrisation is among other factors based on the minimum and maximum temperature between two degauss circles. These two temperatures describe the dependence of the actual field variations on conditions which have occurred in the past.

The effect of railway leakage currents flowing over the vacuum chamber has also been studied. The reproducibility of the leakage current effect on the magnetic field variation was shown by comparing LEP tunnel magnet measurements with test bench results. The effect could be explained by applying the model of small current cycles on excited magnets.

As a consequence of the increased understanding it was possible to model the effect of the field variations due to temperature variations and due to train leakage currents.

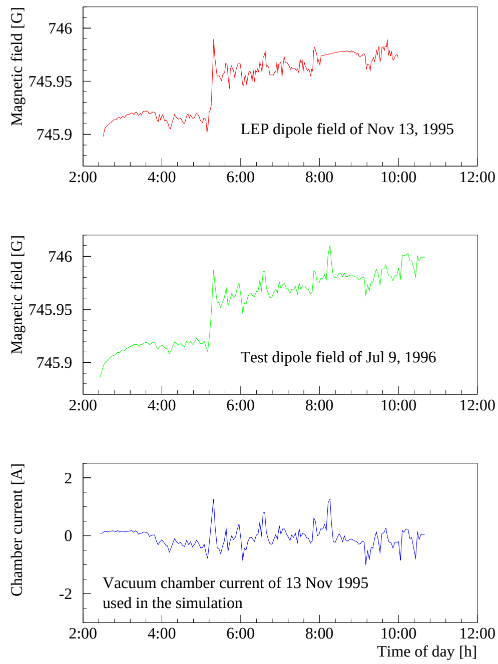

Figure 5: The train effect simulation. The upper plot shows the field evolution recorded in LEP on the 13th of November 1995. The middle plot shows the reproduced field evolution obtained in the ISR test bench. The lower plot shows the current recorded in LEP on November 13, 1995

6 REFERENCES

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