SUPPRESSION OF THE MAIN LEP COUPLING SOURCE

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Abstract

An unexpected magnetization of the thin nickel layer of the LEP dipole vacuum chamber has been identified as the main cause of the large horizontal to vertical optical coupling found during the LEP commissioning. Even though the betatron coupling could be much weakened by changing the difference between the tunes from 8 to 6, it was decided, after some tests, to suppress the source itself by demagnetizing the nickel layer of every chamber. An "in situ" method avoiding a removal of the chambers has been developed. The coupling has been reduced by more than a factor 5. The demagnetization suppresses a constraint on the betatron tunes and weakens the horizontal betatron spin resonances

I. INTRODUCTION

During the LEP injection test, in July 1988, an unexpected phase advance of 2° per cell was found to be due to the shielding effect of a thin nickel layer in the vacuum chamber. Most of this effect was cured by an appropriate shimming of the dipole magnets. But one year later, at the start-up of LEP, a strong betatron coupling was seen [1]. This effect was also due to the nickel layer. If the first effect is due to the permeability of the nickel layer, the second, as we will see below, is due to its large coercivity.

II. THE VACUUM CHAMBER AND ITS NICKEL LAYER

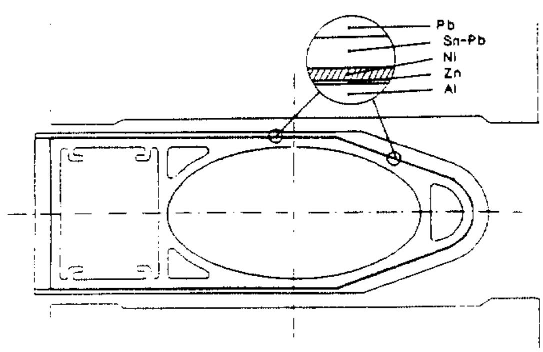

Figure 1: *The LEP dipole chamber and its nickel layer*

To limit synchrotron radiations effects, the aluminium chamber is shielded with lead plates and for corrosion reasons, these plates are tightly clad to the aluminium surface. The two metals are bonded using soft solder; the aluminium surface having been prepared with electrodeposited layers of Zn, Ni and Sn-Pb eutectic (see Figure 1).

The magnetic characteristics of this 7μm nickel layer have been measured with a specially dedicated permeameter. Before applying any excitation field, we discovered on sample slices that this nickel was pre-magnetized at approximately 80% of the saturation field in the transverse direction of the chamber. The exact origin of this magnetization is still unknown but it is sure that it occurred between the lead cladding and reception at CERN. After demagnetization of the samples, we made the hysteresis cycles shown Figure 2.

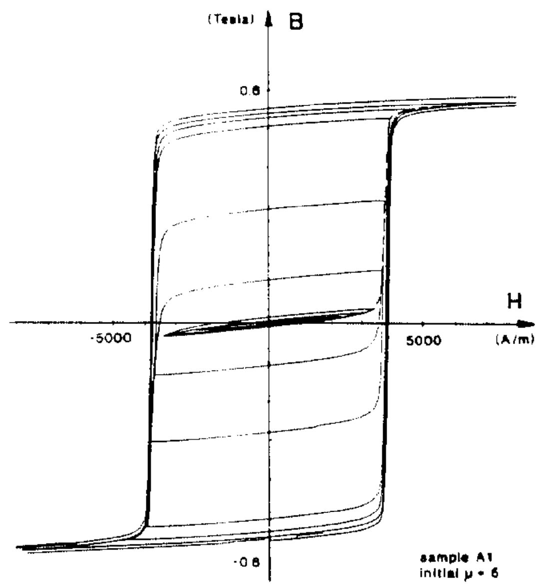

Figure 2: *Progressive hysteresis cycles of the nickel layer*

This Ni layer is a rather "hard" magnetic material ($\mu_0 H_c \approx 60.10^{-4}$ tesla), with a nearly square hysteresis cycle. Once magnetized, a field larger than H_c is necessary to reverse its magnetization. To demagnetize it the decrement of the applied alternating field should be small ($\approx 1\%$). Inversely, once demagnetized, this layer remains insensitive to fields smaller than 80% of H_c.

III. THE ORIGIN OF THE COUPLING

For a thin magnetic layer, only the tangential component of an applied field has an influence on its magnetization. For LEP dipoles, the maximum field on the 60 GeV cycle is 0.0715 tesla, and imposes the magnetization of all but

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the horizontal faces. Even on the 100 GeV cycle (B_{max} = 0.1080 tesla), the pre-magnetization of the two horizontal faces cannot be modified by the dipole field. Figure 3 shows the flux pattern calculated by POISSON generated by the remanent field in the two horizontal faces.

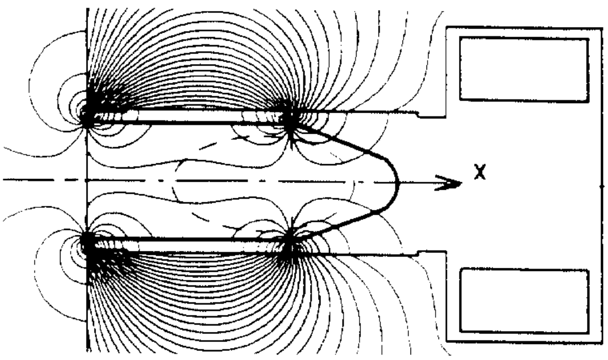

Figure 3: *The flux pattern created by the nickel layer*

An horizontal field gradient is clearly visible. Measurements of this field have been made on short samples of vacuum chamber, by sliding a 14 m^2 area and 40 cm long search coil along the median plane. The results are shown in Figure 4 on the curve labelled "before demagnetization".

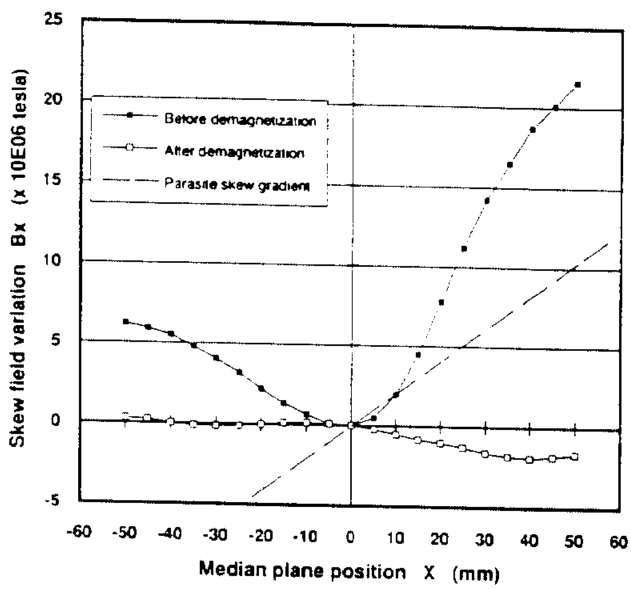

Figure 4: *Variation of the horizontal field measured on samples before and after demagnetization of the nickel layer. The skew gradient necessary for the maximum coupling (2.10^{-4} T/m) is also shown.*

As mentionned in [2], the parasitic source of the LEP coupling is: i) spread along the arcs of the machine, ii) independent of the energy level and, iii) due to a skew gradient of $\approx 2.10^{-4}$ T/m. All these criteria are quite consistent with the behaviour of the nickel layer which is definitely the main cause of the coupling.

IV. The In-situ Demagnetization

To reduce the limitations caused by this coupling, the first action was to compensate it with additional tilted quadrupoles and optics changes [3]. But the parasitic field was not suppressed and some limitations still existed. For this reason, demagnetization of the nickel layer was studied. However, at that time all the chambers were installed in the machine and only a very few were available for sampling. Hence results from the laboratory samples were taken with caution and some margin was incorporated in the design of the method. The demagnetization effect was obtained from a 50 Hz, 0.05 tesla peak field tangential to the layer and decayed simply by slowly displacing the field generator away from the point to be demagnetized. Two systems: i) a solenoid passing along the chamber and ii) a C-shaped magnet sliding along the chamber, were first tested because they were directly powered by the mains but presented a serious drawback in requiring removal of the chamber from its magnet. These systems were used with success to test the efficiency of demagnetization in some places of the machine [4].

A third method not requiring the chamber to be dismantled was preferred for reason of cost and risk. The "in situ" demagnetization is performed by a one turn flat coil excited by a strong alternating pulsed current. This coil, inserted in the gaps between the chamber and the polefaces of the dipoles, is slid at 1 cm/s in the transverse direction to demagnetize the chamber. The current made by a dedicated power supply, is a 2000 A peak current, alternating at 50 Hz and with a pulse duration limited to 1ms in order not to burn the coil. The 20 km of the arcs were demagnetized in four weeks by four teams working in parallel.

Figure 5: *The operation of demagnetization. A set of coils is shown on the right and on the left, a coil, in place on each side of the chamber, is ready for demagnetization*

V. Measurement of the Efficiency of the Demagnetization

Figure 6 shows the result of an arc by arc analysis of vertical oscillations induced by forced horizontal betatron oscillations in a complete arc at a time. It shows a rather large dispersion of the parasitic gradient between arcs, indicating some variation in the production of the chambers and a decrease of the mean value of this gradient by the demagnetization to 19% of its initial value. Considering that 14% of the length of the chambers were not accessible to demagnetization, it is clear that this operation has been an even greater success than expected from the partial tests.

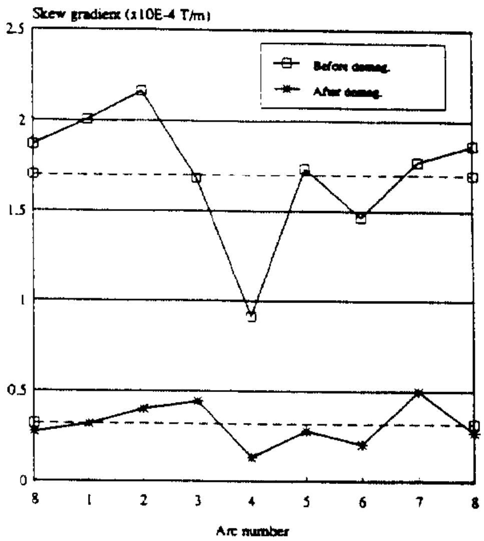

Figure 6: *The average parasitic skew gradient measured arc by arc, before and after demagnetization*

VI. The Improvement of the Machine Behaviour

A. The betatron tunes

The 0th harmonics of the parasitic skew gradient is largely dominant and excites mostly betatron coupling resonances of the type $Q_x - Q_y = 8k$, $k \in \mathcal{R}$ [2]. The nominal betatron tunes of 70.3 and 78.2, chosen to maximize the luminosity, had to be changed, first to 71/77, and later to 70/76 to avoid a systematic resonance driven by the beam-beam forces. The betatron coupling was reduced in this way to its expected value from tolerances on magnetic fields and alignment and could be fully compensated using the available skew quadrupole scheme. However, the constraint on the tune difference makes it impossible to avoid simultaneously the tunes multiple of the machine periodicity in the two planes. Systematic defects were thus amplified in the vertical plane and created initial difficulties. To avoid having to constrain the tune difference, it was shown that the coupling can be minimized by splitting the betatron phase advances by 12° in the standard cell [5]. This however breaks the horizontal achromats, with a possible consequence for the dynamic aperture at very high energy.

The reduction by a factor of 5 of the spurious skew gradient decreases the strength of the strongest coupling resonance from 0.6 [2] to 0.12. This is still high for the skew compensation scheme, but can be combined with a split of the betatron phase advances less strict than in [5]. In 1993, LEP will be operated using an optics with phase advances of 90° and 60° in the horizontal and vertical planes which yields many advantages in addition to coupling compensation.

B. Polarization

The skew gradient was calculated to excite strongly a horizontal betatron spin resonance close to the Z^0 peak. The change of betatron tunes from 71/77 to 70/76 shifted the strongest resonance away from the Z^0 peak. The depolarizing effect of the weaker resonances was minimized by changing the fractional part of the betatron tunes from .3 to .1. After demagnetization (figure 7), the calculated depolarization due to the spurious coupling becomes negligible compared to other sources.

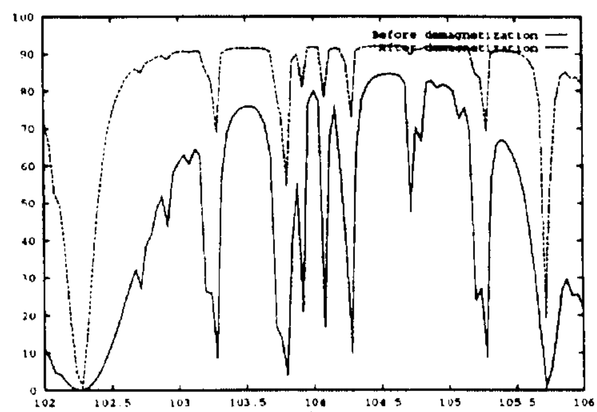

Figure 7: *Depolarization due to the Ni alone before and after demagnetization*

C. Decoupling of trajectories: injection and pretzel scheme

At injection, the skew gradient used to couple the large horizontal injection oscillation into the vertical plane with a compensation only after one turn. With the continuous increase in complexity, it was felt safe to reduce this oscillation. More important is the coupling of the horizontal pretzel separation into the vertical plane. Due to the different trajectories of the electrons and positrons, it results in miscrossings. The demagnetization minimized this effect.

The additional skew quadrupoles which had been installed in the regular cells are now freed to be reconfigured as vertical dispersion correctors.

VII. References

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