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DESIGN OF THE LEP MAIN RING WIGGLERS

by

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Résumé - Il est prévu d'installer huit aimants ondulateurs à trois pôles dans l'anneau principal du LEP au CERN pour avoir des moyens de diminuer le temps d'amortissement à l'injection et pour contrôler l'émittance horizontale du faisceau. La possibilité d'obtenir des faisceaux polarisés est conservée par le choix d'un champ dans les entrefer des extrémités de seulement 40 % de celui de l'entrefer central. L'intégrale de champ égale à zéro est obtenue par l'adaptation des longueurs des pôles. Nous décrivons la conception de l'aimant, ses exigences à l'excitation et ses performances prévues par des calculs magnétiques à trois dimensions.

Abstract - It is proposed to install eight three-pole wiggler magnets in the LEP main ring at CERN, in order to provide a means both for decreasing the damping time at injection and for controlling the horizontal beam emittance. The possibility of having polarized beams at LEP is retained by the choice of a field in the end gaps which is only 40 % of that in the central gap, the pole lengths being chosen to keep the field integral zero. The paper describes the design of the magnet, its excitation requirements and its performance as predicted by three-dimensional magnetic field computations.

I - INTRODUCTION

The LEP main ring at CERN will be equipped with eight wiggler magnets which will make it possible to reduce the damping time at injection and to control the beam emittance during acceleration. These single wavelength wigglers also serve to increase the rate of polarization, but the asymptotic level which can be achieved for this latter parameter is severely reduced unless centre field, $B_+$, and end fields, $B_-$, are substantially different [1]. In order to obtain a zero integral of field along the beam direction, the length of the end poles must be adjusted to the $B_+/B_-$ ratio. Since the magnet is required to work over a wide range of excitation, correction windings must be provided to compensate for the variation of the ratio $B_+/B_-$ caused by the change in saturation.

II - DESIGN CRITERIA

For the design computations, the following parameters (y and z are here the longitudinal and vertical directions) must be considered:

$$\int_{-\infty}^{\infty} B_z \, dy$$
the field integral, which should be zero over the full useful aperture;

$$\int_{-\infty}^{\infty} |B_z| \, dy$$,
this integral is a measure of the emittance control capability;

$$\frac{B_+}{B_-}$$
the ratio between the centre and end fields, determining the ratio of the sum of the lengths of the end poles to that of the centre pole $L_-/L_+$. 
This ratio should be as high as possible in order to minimize reduction in polarizaton. Its effectiveness in this respect, however, goes asymptotically and above a certain level considerations of constructional feasibility prevail.

In addition to these parameters, we have the following constraints: gap height, 100 mm; useful aperture in the transverse direction, 120 mm; maximum field (imposed by synchrotron radiation, but also convenient for reasons of saturation), ~1.0 T; height of median plane above floor, 0.65 m; maximum total width, 0.7 m.

III - WHY NOT THREE DIPOLES?

The wiggler function could be obtained by using separate dipole magnets and powering them such that over three units the integral becomes zero. The advantage of this arrangement is that all dipoles are magnetically independent. The drawback, however, is that their cross-section becomes rather large, especially for the centre magnet, since the return flux of a 1 T magnet has to be guided around the beam line.

The other solution, which is elaborated upon here, consists of using the return flux of the centre unit to provide the field in the end gaps. Although this is elegant from the point of view of space utilization, it has the disadvantage of magnetic interconnection between centre and end parts, which makes compensation coils necessary.

IV - CHOICE OF POLE, YOKE AND COIL DIMENSIONS

The main initial choice is the ratio between length of end poles and centre pole. A reasonable compromise for the value of \( L / L_p \), in a first approximation equivalent to \( B_s / B \), is found to be 2.5. This allows a sufficient degree of polarization without requiring unreasonable pole dimensions. Limiting ourselves to a total magnet length of about 3 m, the length of the centre pole was chosen - for the computations - to be 0.76 m and that of each end pole to be 0.96 m. A width of 0.28 m was found to be adequate for the poles. For a central field of 1 T and particle beam height of 0.65 m, the yoke needs to be somewhat larger (0.36 m).

In order to reduce eddy-current effects, the yokes and the pole pieces have to be laminated. Whereas it is sufficient for our purposes to use 50 mm thick plates, and these have been chosen for the longitudinal yoke bars, considerations of cost and field uniformity led to the choice for the poles of 1.5 mm thick sheets, aligned perpendicularly to the beam direction.

The coils taken for the computation have an overall cross-section of 235 mm x 110 mm and 235 mm x 50 mm for the centre and end coils respectively. The cross-section of the end coils is larger than one would expect from the field ratio, because they include correction windings. These additional windings are incorporated in the end coils because they are more efficient there and an increase in the overall width can be avoided. Furthermore, it was considered useful to have two parameters free in case of asymmetry in the distribution of magnetic flux between the two end poles.

A perspective view of the magnet is shown in Fig. 1.

V - COMPUTATIONS

The nature of the wiggler is such that three-dimensional computations are necessary in order to determine how, for a given ratio \( L / L_p \), the corresponding ratio \( B_s / B \) varies over the range of excitation, and how the ratio of amp\'re-turns in centre and end coils must vary to keep the field integral zero. The latter information is required for final optimization of the coil system. These calculations are necessary to study how the field integrals vary over the aperture, and how to shim. The computations were made by means of the program PROFI (developed by W. Müller at the Darmstadt Technische Hochschule), which applies the finite difference method in
three dimensions and allows to solve problems with nonlinear materials. The results can be grouped into those which determine the operation, i.e. powering of the wiggler coils, and those which predict the magnet performance.

VI - WIGGLER POWERING

Figure 2 shows the variation of the field along the axis of the magnet. For an ideal wiggler, the integral of this function must be zero. Although this is required over the full aperture, we first consider only the integral along the axis. It is found that the ratio of the ampère-turns in end and centre coils, $I_e/I_c$, which is required to maintain a zero field integral over the excitation range, is not constant (Figs. 3 and 4). Since it is preferred to power the coils in series, quite substantial auxiliary windings must be foreseen (Fig. 5).
VI – WIGGLER PERFORMANCE

Figure 6 shows the maximum induction in the magnet centre as a function of centre coil excitation when the end coils are powered to keep the integral zero. In the same diagram, the ratio B/B is plotted. Comparing the current ratio in Fig. 4 with the field ratio in Fig. 6 it can be seen that they differ considerably. The longitudinal integral of |B| versus excitation is shown in Fig. 7.

With lateral shims of cross-section 25 mm x 0.25 mm, the greatest variation of the integrals over the usable aperture of ± 60 mm is calculated to be 2 10⁻³ T for \( \int B_z \, dy \), and -5 10⁻³ T for \( \int |B_z| \, dy \), both at maximum excitation.

VII – CONCLUSION

The diagrams presented give a reasonable picture of the behaviour to be expected of the wiggler. It will be the purpose of model measurements scheduled for just after the conference to make the final adjustment using shims. The computer simulation gives confidence that the envisaged wiggler will satisfy the requirement, and provides estimates of how the main and auxiliary power supplies must be controlled in order to achieve the desired zero field integral.

REFERENCE