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WIGGLERS FOR CONTROL OF BEAM CHARACTERISTICS IN LEP

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Summary

Eight three-block dipole wigglers will be used in
LEP to maximize luminosity and control other beam para-
meters such as emittance, damping rates at injection,
energy spread and polarization. The excitation law for
constant emittance (chosen, for example, to fill the
dynamic aperture) and damping partition numbers is giv-
en. In contrast to conventional wigglers where orbit
perturbation is avoided by means of a series of equal
fields of alternate polarity, the LEP wigglers will use
unequal fields and pole lengths. This allows one to re-
tain a high potential asymptotic polarisation level to-
gether with an increased polarisation rate. The choice
of the degree of field asymmetry is imposed by limita-
tions on the transverse dimensions of the magnets and
field levels, by polarisation requirements and by
cost. A practical design of the proposed wiggler is
presented.

1. Emittance Control

In an electron-positron storage ring with fixed
optics, the emittances and energy spread of the beam
are uniquely determined by the operating energy. Put-
ting in a dipole wiggler makes it possible to have lar-
ger energy spreads and emittances than these "natural"
values[1]. When the possibility of increasing the coupled
horizontal emittance, ε_{xc}, by reducing the damping par-
tition number, J_x, is exhausted, a wiggler allows the
storage of larger currents before reaching the beam-
beam limit (assumed to correspond to a definite value,
e.g. $\xi = 0.03$, of the linear tune-shift parameter). To-
gether with the requirement of keeping the occupied re-
gion of phase space sufficiently within the dynamic (or
physical) aperture, this leads to the prescription of
constant $\varepsilon_{xc} = \hat{\varepsilon}_{xc}$ for maximum stored current at energy
$E < \hat{E}$. This is the energy at which the dynamic aperture
constraints are just fulfilled with the lowest toler-
able value of J_x (0.5, for example) and the wiggler un-
excited. In the high-luminosity configurations of ma-
chines like LEP, the dynamic aperture is generally
smaller than the physical aperture for $E < \hat{E}$. With
standard notations:

$$\varepsilon_{xc} = \frac{1}{1 + \kappa^2} \frac{55}{32 \sqrt{3}} \left(\frac{\hbar}{mc}\right)\left(\frac{E}{mc^2}\right)^2 \frac{I_5^0 + I_5^W}{J_x (I_2^0 + I_2^W)} ,$$

where I_i^5 and I_i^W (i = 1, ..., 5) are the contributions
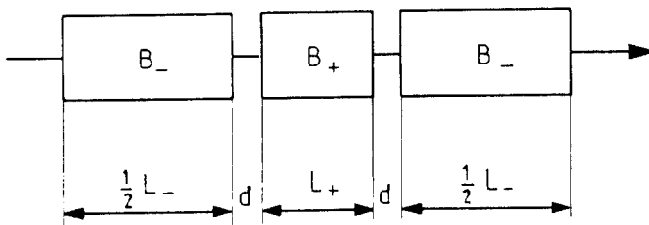of the lattice and the wiggler to the synchrotron inte-
grals, respectively.

Fig. 1 Model used for calculations.

With N_s of the wiggler installation shown schematically
in Fig. 1, and setting $r = L_-/L_+$:

$$I_2^W = N_s L_- (1 + r) G_-^2 , \qquad \text{and}$$

$$I_5^W = N_s L_- (1 + r^2) <W>_w |G_-|^3 ,$$

where $G_- = G_+/r$ is the inverse of the bending radius in
the outer '-' blocks of the wiggler. The function

$$W = \left[D_x^2 + \left(\beta_x D_x' - \frac{1}{2} \beta_x' D_x\right)^2 \right] / \beta_x$$

is changed by the excitation of the wiggler but this
can be neglected in the cases of interest.

Neglecting the energy lost by synchrotron radiation
in the wiggler in comparison with that in the rest of
the machine allows one to solve the equation for
constant emittance and gives:

$$B_-(E) \simeq \pm \frac{1}{ec} \left[\frac{I_5^0}{N_s (1 + r^2) L_- <W>_w} \right]^{\frac{1}{3}} \tilde{E}, \quad B_+ = -rB_- ,$$

where $\tilde{E}$ is the geometric mean of $\hat{E} - E$, E and $\hat{E} + E$.
This excitation provides maximum luminosity with
colliding beams and need not be followed during
ramping. Injection can also be facilitated by using a
high field level to increase damping rates.

The solid curve in Fig. 2 shows how the required
wiggler field varies as a function of energy. It is
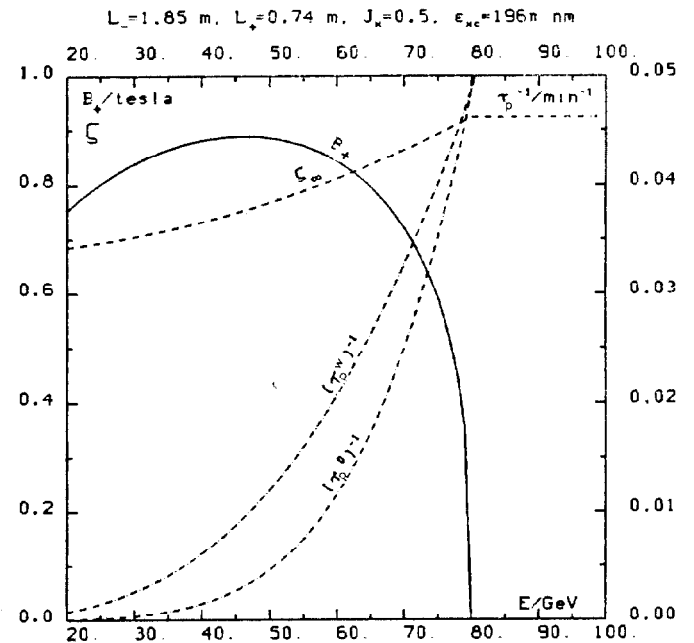interesting to note that the highest wiggler field
occurs at $E = \hat{E}/\sqrt{3}$.

L_=1.85 m, L_+=0.74 m, J_x=0.5, ε_xc=196π nm

Fig. 2 Typical curves of required wiggler excitation
and corresponding polarization

2. Polarization

It is well known[2] that the polarization rate is increased by a wiggler. Using our notation, the enhancement factor with constant emittance can be written

$$\left(\frac{\tau_p^w}{\tau_p^0}\right)^{-1} \simeq 1 + \frac{<W>_0}{<W>_w}\left[\left(\frac{\hat{E}}{E}\right)^2 - 1\right] ,$$

$< >_0$ being an average over the main bending magnets. However, it is also well known that any reverse bending reduces the asymptotic polarization level (neglecting all depolarizing effects)

$$\zeta_\infty = \frac{8}{5\sqrt{3}} \int G(s)^3 \, ds \bigg/ \int |G(s)|^3 \, ds .$$

With our wiggler and constant ε_{xc}:

$$\zeta_\infty = \frac{8}{5\sqrt{3}}\left\{1 - \frac{2r^2}{(1+r^2)}\frac{(\hat{E}^2 - E^2)}{\left[E^2(<W>_w/<W>_0 - 1) + \hat{E}^2\right]}\right\}$$

provided the '-' sign has been chosen in the expression for $B_-(E)$. Thus, the bigger r is, the less the maximum polarization is reduced, provided the field in the '+' block points in the same direction as the field of the main bending magnets. For $r = 1$ or $B_- > 0$, ζ_∞ is severely reduced.

3. Choice of Wiggler Geometry

The maximum values of the wiggler fields B_+ and B_- and their ratio r have been chosen to provide sufficient capacity for emittance control in all optics of both the 60° and 90° phase advance versions of LEP, and to retain the possibility of having useful degrees and rates of polarization. Further constraints come from considerations of synchrotron radiation, available space and, of course, the cost of the units.

The wiggler system will consist of eight identical magnets, each having $r = 2.5$, $L_+ = 0.74$ m and $B_+ \leq 1$ T, and its physical design is shown in Fig. 3. The magnet is made in two halves separated by four non-magnetic pillars, each half consisting of three poles fixed to a rigid steel beam (yoke). Excitation is provided by aluminium coils around the poles. Whereas the coils around the centre poles consist of a main, water-cooled winding only, the end coils incorporate main and auxiliary windings. The latter serve to trim the field to give a rigorously zero field integral at all current levels. All the main windings are connected in series, as are the auxiliary windings, to give one high- and one low-current circuit (600 A and 75 A). Shims are placed at the pole edges to ensure that the field integral is zero across the useful aperture (± 60 mm) of the magnet. Yoke and poles are laminated to avoid field quality problems due to eddy currents, when the field is changed with stored beams present. The poles are 280 mm wide, and the gap ·is 100 mm high.

The flux configuration in this magnet is such that it is necessary to use fully three-dimensional field computation codes to determine steel and coil geometries. This has been done, and the detailed magnetic design will be described elsewhere[3]. The computed maximum vertical field along the beam path over half the magnet's length is shown in Fig. 4. The total excitation which is required for centre and end coils in order to obtain a zero field integral is shown in Fig. 5.
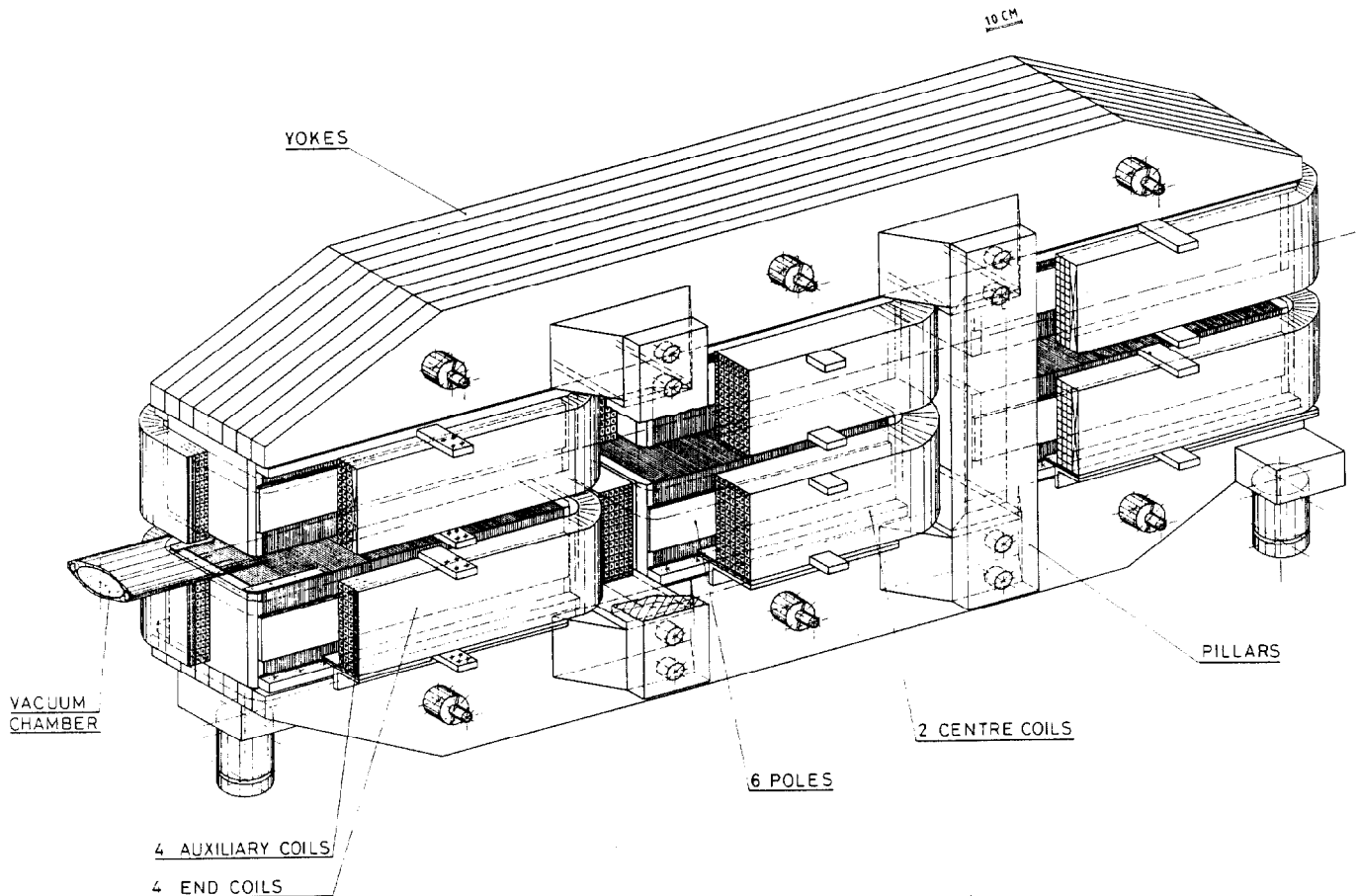

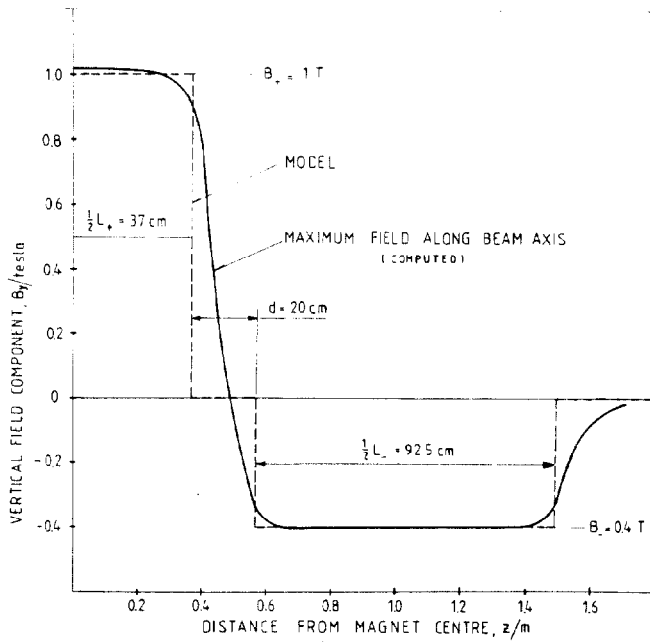Fig. 3 Proposed LEP wiggler magnet

Fig. 4 Computed field over half the length of the magnet.

Fig. 5 End coil vs. centre coil excitation for no net effect on the closed orbit.

4. Optical Properties

The trajectory of the beam through the wiggler is such that edge focusing will occur at the passages from − to + and from + to − fields. Whereas the effects are self-compensating in the horizontal plane, in the vertical plane they add, and the wiggler acts as a thin focusing lens. In the worst case, i.e. at injection energy (20 GeV) and with the wiggler fully excited, the focal length of this lens is 4300 m: this gives rise to a slight mismatch of the vertical beta function and a total vertical Q-shift of about 0.01 for the ensemble of eight magnets. It is foreseen to compensate for this either by applying a general correction, or by matching, using nearby quadrupoles. The latter method is facilitated by the fact that, as the wigglers will be installed at the lattice end of the dispersion suppressor, the closest quadrupoles are individually controlled, independent of the lattice strings.

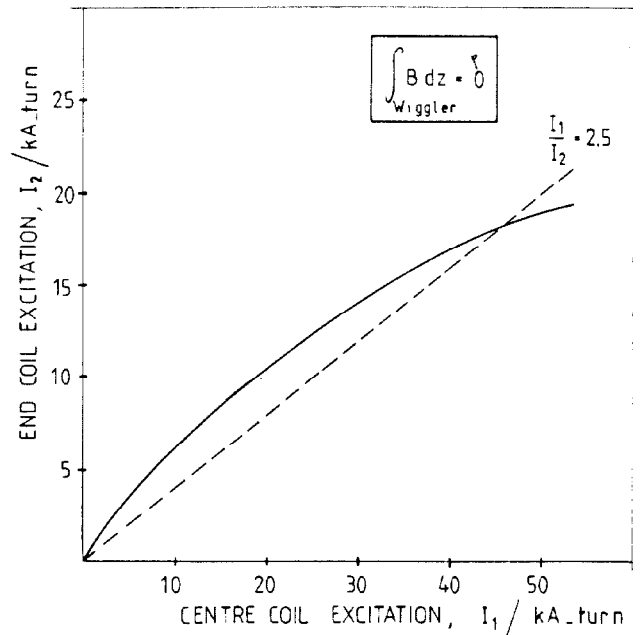The maximum sagitta in the wiggler, occurring at injection, is estimated to be 4.7 mm. In order to minimize the required horizontal aperture, the wiggler magnets will be located near to vertically focusing quadrupoles, i.e. where β_x is small. Such a location of the magnet is also favourable for spreading the synchrotron radiation in the vertical plane.

References

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3. T.M. Taylor and T. Tortschanoff, Paper to be submitted for publication to the 8th Int. Conference on Magnet Technology (MT-8), Grenoble (1983).