The Polarization Wigglers in LEP

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Abstract

Twelve strong wigglers, primarily intended to increase the polarization rate and level, were installed in LEP during the 1990–91 shutdown. At injection energy in particular, the effects of synchrotron radiation in these wigglers completely dominate those from the rest of the ring. Their design and commissioning are described. Among several applications, the substantial controlled bunch-lengthening of which they are capable has proved to be important in increasing the intensity of the LEP beams. The measured effects of the wigglers on the beams and vacuum are compared with theoretical predictions.

1 INTRODUCTION

In e^+e^- storage ring colliders which are intended to operate over a range of energies, wigglers are an extremely useful tool to increase the accessible range of beam parameter-space. They can be used to offset unfavourable "natural" energy-dependences of parameters such as the luminosity, $L \propto E^4$, the radiation damping rates, $1/\tau_{x,y,\varepsilon} \propto E^3$, or the Sokolov-Ternov radiative polarization rate $1/\tau_p \propto E^5$.

For budgetary reasons, the original configuration of wigglers for LEP [1] was limited to providing sufficient flexibility to optimise injection and maximise luminosity.

Later, when a considerable interest in polarized beams emerged, an additional set of wigglers, now known as the "polarization wigglers" were proposed [2]. These were designed to produce the maximum possible enhancement of the polarization rate compatible with the physical aperture of a standard LEP optics with 60° betatron phase advance per arc cell. Their contributions to the energy spread, bunch length and polarization rate, as measured by the standard synchrotron radiation integral I_3 [3] (see Figure 1) completely dominate the rest of the ring, particularly at the injection energy of 20 GeV.

This paper describes the magnet design and first experience with these wigglers after they were installed for the 1991 LEP run.

2 DESIGN, CONSTRUCTION AND TESTING OF THE MAGNETS

The concept of the magnet is based on the requirement to have a highest reasonable ratio of end pole to centre pole lengths, L_-/L_+; together with the highest reasonably achievable integral of $\mathbf{B}^3$. The major constraints are space (cell-length),and the need to keep the integral of B_y

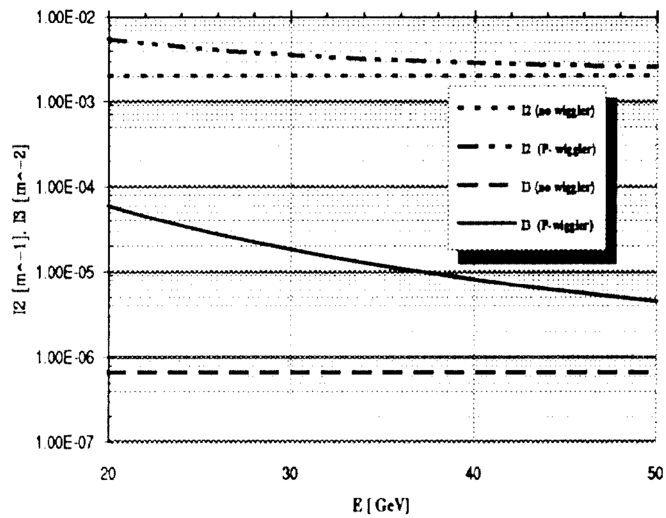

Figure 1: Synchrotron radiation integrals $I_2 = \int G^2\, ds$ and $I_3 = \int |G|^3\, ds$ as functions of energy with and without the 12 polarization wigglers at maximum field.

Centre magnet peak field	1.359	Tesla
End magnet peak field	0.168	Tesla
$\int B_y\, ds$ in centre magnet	1.016	Tm
$\int B_y^2\, ds$ in centre magnet	1.237	T^2m
$\int B_y^3\, ds$ in centre magnet	1.600	T^3m
Effective length ratio L_-/L_+ (B)	8.01	
Centre pole length L_+	0.62	m
End pole length L_-	2.88	m
Centre-end pole separation	0.37	m
Closed orbit displacement (20 GeV)	14	mm
Pole gap height in centre magnets	94	mm
Pole gap height in end magnet	100	mm
Total length of wiggler	7.25	m
Total power per wiggler	42	kW
Nominal main coil current	500	A
Maximum current in trim coils	±55	A
Mass of central magnet	4.9	t
Mass of one end magnet	2.5	t

Table 1: Parameter list for polarization wiggler magnets

zero while limiting the orbit displacement inside the wiggler to below 15 mm. Furthermore, besides being of the lowest possible cost, the complete system had to be up and working within the stringent time limits linked to the shut-down schedule of LEP.

Each of the 12 polarization wigglers (Fig. 2) is made

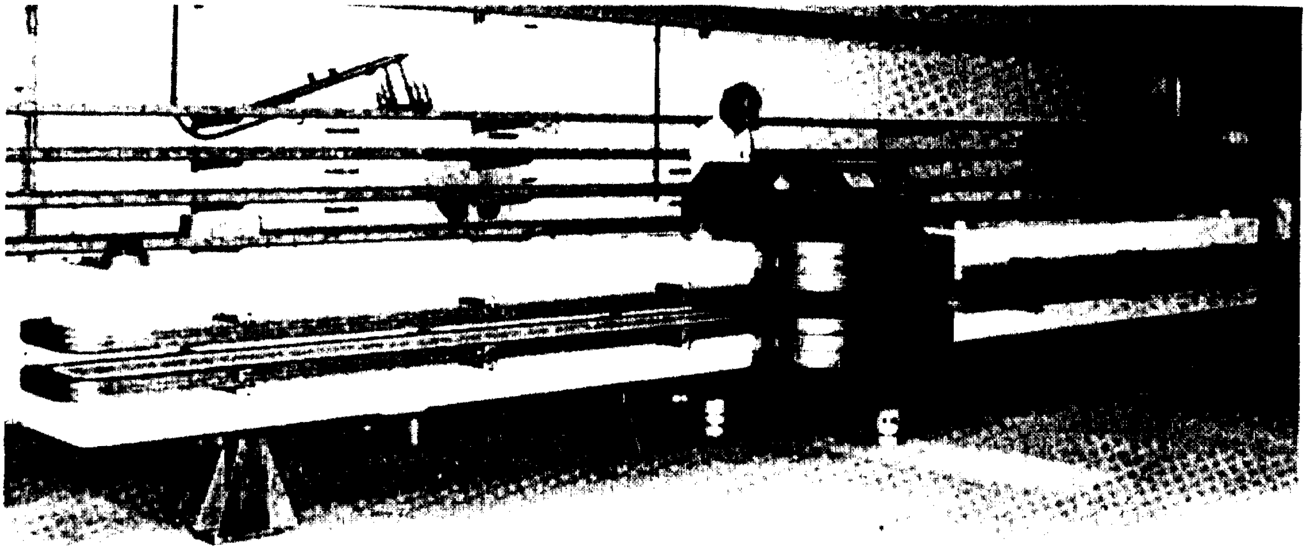

Figure 2: A polarization wiggler during tests.

up of three independent dipole magnets: a 1.35 T strong centre unit having a pole length of 0.62 m and two 0.16 T end magnets. The centre dipole is of the C-type because of transverse space limitations in the LEP tunnel. The field and length of the end dipoles correspond to (half) iron-concrete cores as used for the main LEP bending magnets. Thus, while the centre magnets had to be newly fabricated, the end dipoles could be constructed from a reserve of spare yokes, which only had to be cut in two and equipped with specially made end-plates and coils. This gives an end-pole length of 2.88 m per side. The distance between the poles is 0.37 m.

The combining of magnets of such different characteristics as the high field centre magnet and the very low field iron/concrete core magnets, together with the need to excite the magnets in series, made trim coils for the balance of the field integral indispensable. The trim windings are part of the end magnet coils and cover about ±10% of the main excitation. In order to be compatible with the cooling circuit of LEP, the main coil windings are made using hollow aluminium conductor. The trim coils are wound from solid conductor indirectly cooled via the main windings, by potting in a common mould. The main parameters of one wiggler unit are shown in Table 1. It is important to note that effective lengths for B, B^2 and B^3 are different. While the B integral of the centre magnets determines the length of end magnets and their excitation, using the same effective lengths for the calculation of the integral of B^3, the parameter which controls the rate of polarization, would lead to a 15 % overestimate of the effect.

The polarization wigglers are installed in dispersion-free straight sections around LEP insertion points 3 and 7, near vertically focusing quadrupoles. This minimizes the effect of the bump in the closed orbit and opens the possibility of local compensation of vertical focusing due to the wigglers. By their location and by the use of special collimators, an excessive concentration of energy incident on the vacuum chamber due to their production of strong synchrotron radiation could be avoided.

Six wigglers assemblies around one interaction point are powered in series, both for the main coils and the trim coils. It was therefore necessary to take care to combine the magnets according to the results of the magnetic measurements in order to minimise residual distortion of the closed orbit. This method of operation has been found to be satisfactory in practice, with only minimal correction required from the adjacent orbit correcting dipoles.

3 EFFECTS ON BEAM

The wigglers have not yet been used for their main purpose of accelerating the radiative polarization process but have been used at injection to lengthen bunches. In 1991, there was also not enough RF voltage to switch them on at full field at 46 GeV.

It proved to be difficult to fully excite the wigglers on the 60° lattice without making the beam lifetime very short. This was achieved only once [4] with only 6 of the wigglers and many adjustments of the injection bump, orbit and tunes. On a 90° lattice, however, it was possible to excite all 12 wigglers to their maximum field. Moreover this controlled method of bunch-lengthening was beneficial for longitudinal stability in the 90° lattice and allowed high currents to be stored. A possible explanation [5], based on modelling the multipole components in the dipoles is the different chromatic behaviour of the tunes in the two lattice (recalling that the fractional energy spread $\sigma_\varepsilon \propto \sqrt{I_3/I_2}$ we see from Figure 1 that the effects of the wigglers can be dramatic).

At 20 GeV, the wigglers change the natural (low-

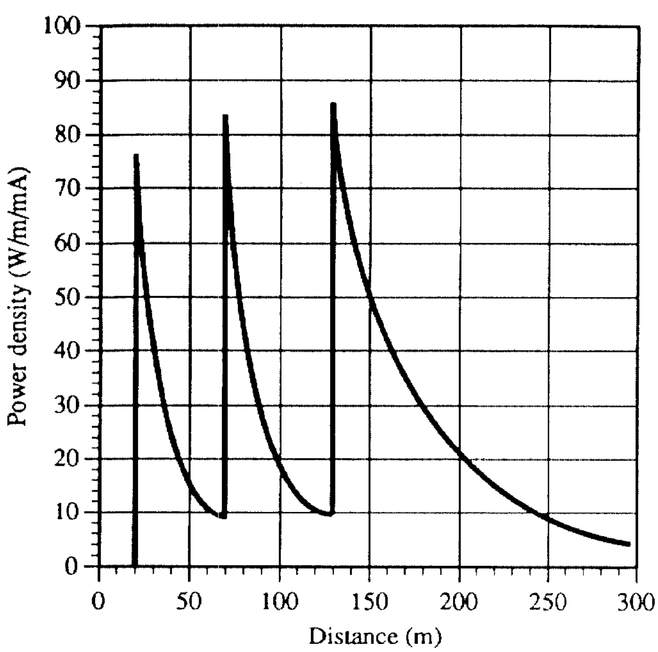

Figure 3: Power density (W/m/mA) along one side of the vacuum chamber downstream of a set of 3 wigglers, calculated for one beam of 47 GeV, 1mA beam current and 1.3T central field.

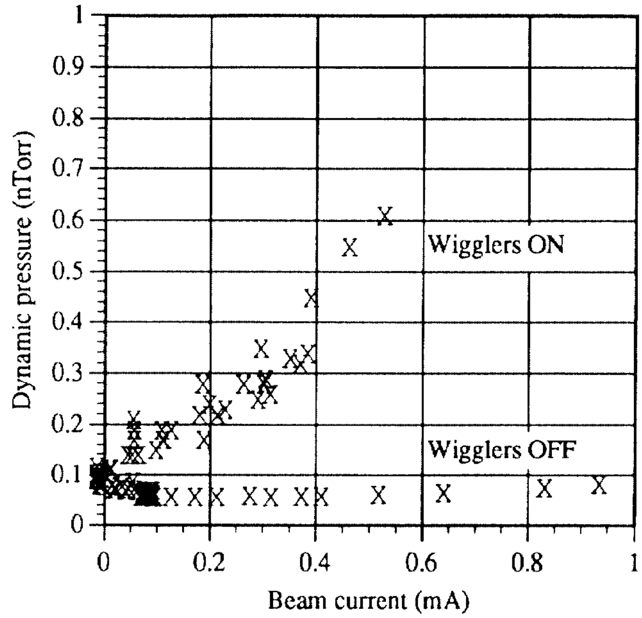

Figure 4: Effect of the wigglers on the dynamic pressure (nTorr/mA) as a function of the beam current.

intensity) bunch length from $\sigma_z \simeq 3\,\mathrm{mm}$ to $\sigma_z \simeq 17\,\mathrm{mm}$. Without the wigglers, bunch-lengthening occurs at low currents with the associated longitudinal instability. The wigglers create a much more stable situation which allowed currents of up to $I_b = 560\,\mu\mathrm{A}$. Streak camera measurements confirmed the predicted bunch length.

4 EFFECTS ON VACUUM

4.1 *Power deposition on the vacuum chamber*

The synchrotron radiation power from the polarization wigglers illuminates both sides of the vacuum chamber in the horizontal plane. The power density per mA beam current from one group of 3 wigglers on one side wall of the vacuum chamber is shown in Fig. 3. for 47 GeV beam energy. The vacuum chamber cooling capacity in the arcs of LEP has been designed for a linear power density of up to 1.4 kW/m by a symmetric arrangement of 3 cooling water channels—a main cooling channel in the 'nose' of the vacuum chamber, where the main power is deposited and two additional channels on the 'back' of the chamber for removing scattered radiation and the heat generated during the activation of the NEG pumps. At the polarization wigglers this average power level may be exceeded locally by up to a factor of 2 when LEP operates in the future with 8+8 bunches. The resulting temperature rise of the vacuum chamber remains acceptable. However, since any step of the aperture leads to a strong concentration of the power deposition, special care has been taken to guarantee a uniform, smooth chamber section. For this reason aperture limiting collimators in LEP had to be relocated to wiggler free sections of the machine.

4.2 *Dynamic pressure rise*

A significant increase of the vacuum pressure can be observed due to the intense synchrotron radiation which strikes the vacuum chamber in the otherwise radiation-free straight sections of LEP. Since in normal operation these parts of the vacuum system had not been exposed to radiation, the cleaning effect due to photon desorption in the arcs of LEP was largely absent. Figure 4 shows the change of the vacuum pressure due to the wiggler radiation in one of the electrostatic separator tanks at the crossing point 3. Without the wiggler radiation, the pressure remains stable below 5×10^{-11} Torr, independent of beam current. With the wigglers switched on, a strongly increased pressure rise with up to 6×10^{-10} Torr/mA can be observed. This value has to be compared with the dynamic pressure rise of only 7×10^{-11} Torr/mA which has been reached in the arcs of LEP during operation.

Acknowledgements

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5 REFERENCES

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