SEXTUPOLAR AND DIPOLAR POLE FACE WINDINGS AT LEAR

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Abstract

To increase the dynamic aperture of LEAR, especially at low energy (down to 2 MeV) combined sextupoles and vertical dipoles were built and installed. The only possible location (zero-dispersion region) implied construction of pole face windings inside the bending magnets. This paper describes the characteristics of these magnets and their influence on beam behaviour.

Introduction

The CERN Low Energy Antiproton Ring (LEAR) delivers beam to physics experiments at momenta between 105 MeV/c and 2 GeV/c with spill lengths of 10 min to 5 h leading to particle fluxes of 10^4 to 2×10^6 p/s [1]. The sextupoles are then an important tool to set the desired chromaticity (~(0, 0) in both planes for storage mode or (0.6, 0) for slow extraction). Unfortunately, the original sextupole configuration gives large non-linear coupling, limiting the transverse dynamical acceptance and therefore the beam life time especially at low momenta. Adding sextupoles (1985 sextupoles configuration) in a location where dispersion is non-zero reduces non-linear coupling, but increases the second-order [3] chromaticity. As this space is required for internal experiments and there was also strong request for lower momenta (61.2 MeV/c i.e. only 2 MeV of kinetic energy), it was decided to add new sextupoles in a non-dispersive region, along with vertical dipoles to give flexibility in orbit manipulation at the jet-set experiment, at the electron cooling device, as well as improving orbit correction.

The Pole Face Winding (PFW)

The only possible location for these correction coils was found to be in the end blocks of the bending magnets where dispersion crosses zero, and the phase for non-linear coupling correction is good. This meant increasing the gap of the magnet by 7.5 mm. The gap of 8 mm existing in the yoke was filled with iron in order to conserve the magnetic field in the main gap. The coils are placed on the pole profile [3] of the LEAR C-type bending magnet (Fig. 1).

The sextupole windings consist of 28 conductors and their returns. The conductors are positioned symmetrically about the center of the gap, while the returns are placed parallel to the gap chamfers. This arrangement produces a small dipole field which can be almost compensated for by adding a single turn coil around the core, connected in series with the sextupole windings.

The dipole windings for vertical orbit correction consist of 16 turns. The conductors are sitting on the pole faces in between the sextupole windings. The upper and lower parts of this coil are connected together at their extremities in a fold-up head. The two coils follow the general curvature (R = 4.17 m) of the magnet. They were moulded together in epoxy resin under vacuum.

The complete fabrication of the 8 PFW's was undertaken at CERN. This included the design and manufacture of the 3 forming jigs together with the vacuum casting mould in which the combined sextupole and dipole were impregnated.

The first coil was successfully moulded within 6 months after the acceptance of the design study, which testifies to the excellent cooperation between the various services involved and an unfailing commitment by everyone to meet the 1990 January shutdown.

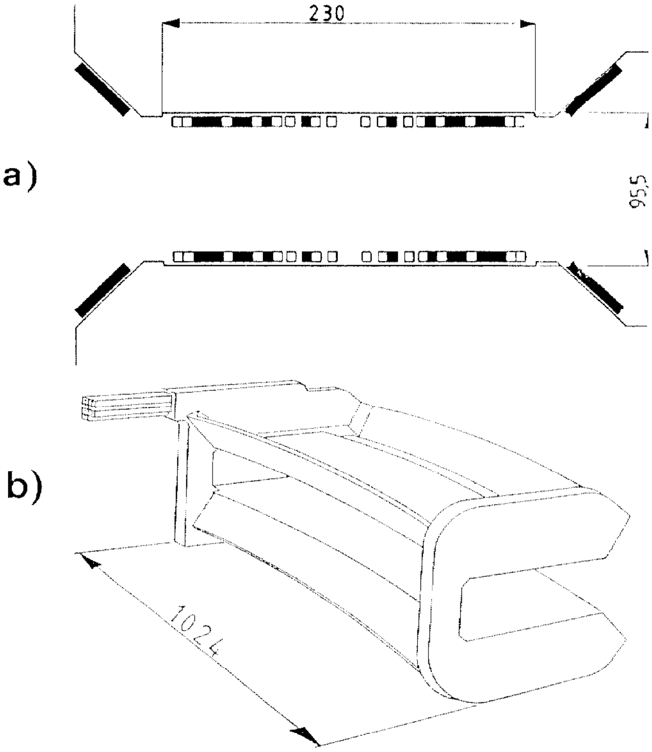

Fig. 1 - Pole face winding overview.
a) Transverse section of the winding showing the position of the conductors (black squares for sextupoles, white squares for vertical dipole).
b) A general view of the final moulded coil.

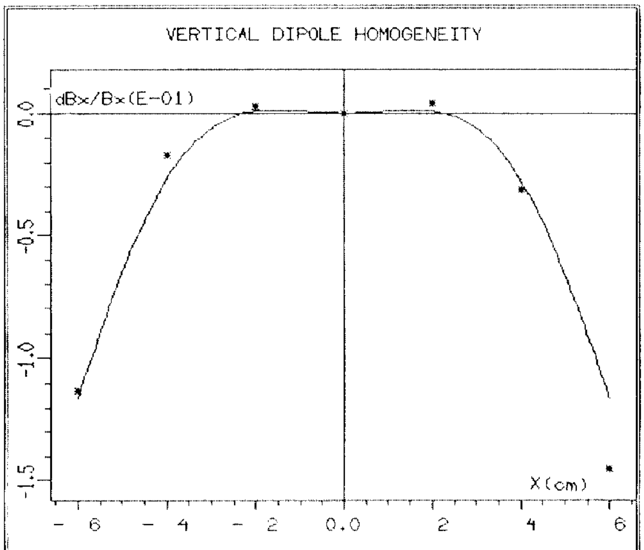

Fig. 2 - Theoretical (-) and measured (*) magnetic characteristics of the dipole.

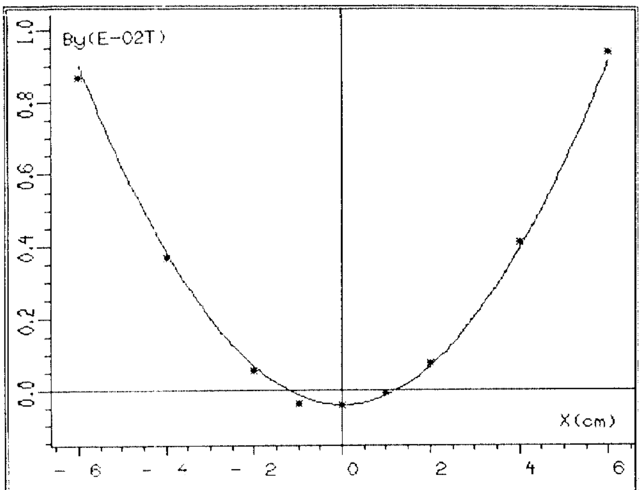

Fig. 3 - Theoretical (-) and measured (*) field of the sextupole.

The PFW Magnetic Properties

The magnetic and electrical properties are shown in Table 1 while the magnetic field qualities are shown in Figs 2 and 3. The measurements were done by moving a hall probe along the magnetic radius of the bending magnet [4].

	Dipoles	Sextupoles
Nominal current	150 A	150 A
∫Bdl or ∫k'dl	130 Gm	5.4 Tm/m^2
Resistance/coil	0.067 Ω	0.90 Ω
Voltage/coil	11.3 V	13.5 V
Water cooling	1.4 ℓ/min	1 ℓ/min
At pressure drop	8 atm	4 atm

Table 1 - Main Properties of the PFW's

The First Results on LEAR

Using a suitable compensation scheme for the systematic resonance $Q_H+Q_V = 8$, which is the main component of the non-linear coupling, we have measured the chromaticity of the machine (Fig. 4). The second-order vertical chromaticity has been decreased by a factor 6. The remaining component comes from pseudo-octupoles [5] (end field of the quadrupoles).

At LEAR, the non-linear coupling is responsible for the tune dependence on betatron oscillation amplitude of particles. This was also measured by kicking horizontally a well cooled bunched beam, acquiring the oscillations and treating them by FFT techniques [6] (Fig. 5). With the original sextupoles configuration, the horizontal tune changed only weakly with transverse displacement but the vertical tune had a huge dependence (17×10^{-3} for kick of only 2.5 mrad).With the new sextupoles, the vertical tune dependence is reduced by a factor 5. At the same time we have recorded the loss rate after the kick (Fig. 6). No losses were seen for the first second even for $2J_X = 175$ mm.mrad ($2J_X = x'^2_k \beta_k$ is the invariant of the oscillation; x'_K: kick amplitude, β_K: Twiss parameter at the kicker) indicating a large horizontal acceptance. After the kick the stochastic cooling proceeds. We can evaluate the dynamical acceptance to 60π mm.mrad which is much better than original sextupole configuration. For larger kick we can lose a major part of the beam which is sitting on high-order resonances or crossing them during cooling.

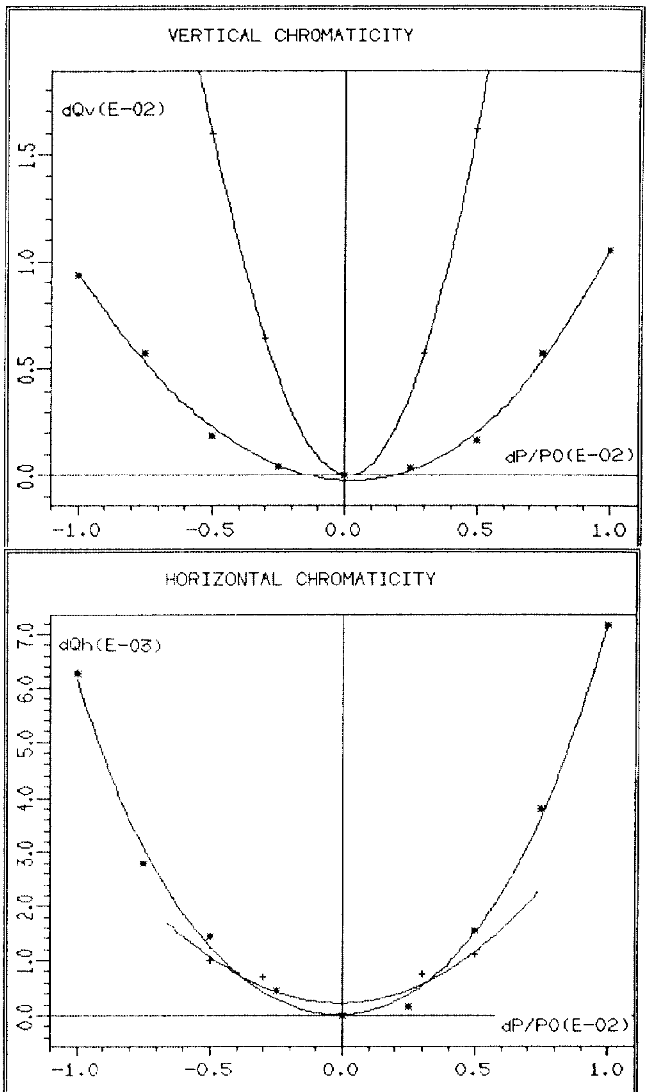

Fig. 4 - Chromaticity at LEAR.
+ 1985 sextupole setting.
* New setting with PFW's.

As for the 1985 configuration the beam lifetime was increased to more than 1 hour at 105 MeV/c with PFW's [2] and more than 20 minutes at 61.2 MeV/c, of course under stochastic cooling [7]. The ultra-slow extraction profits from this improvement in overall and instantaneous efficiency as well as in beam quality. During the last turns before extraction, particles perform large betatron oscillation amplitude in the horizontal plane. If there is non-linear coupling, the particles get non-linear motion in the vertical plane and are finally lost due to the small vertical acceptance of the LEAR machine (< 50 π mm.mrad).

Further studies will be done to compensate completely for the non-linear coupling and better results will be looked for. The enormous sextupole installed in LEAR (26 sextupoles of 5 T/m^2 each) probably permits us to study long-term beam behaviour.

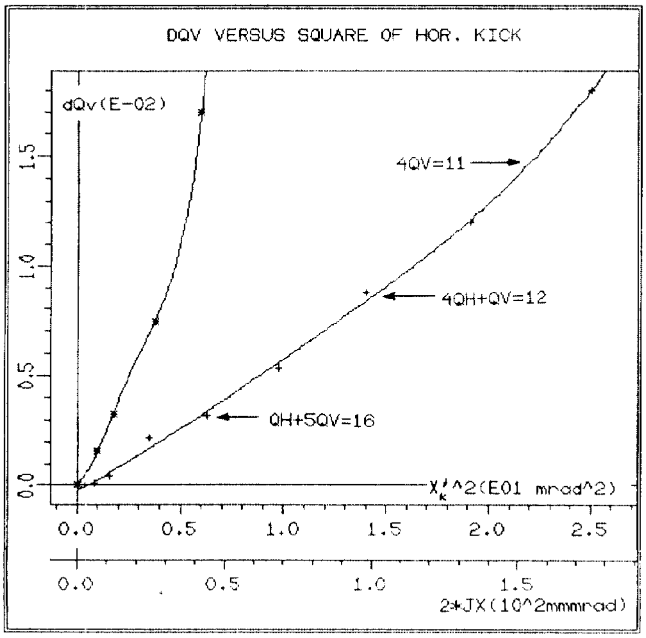

Fig. 5 - Vertical tune variation with the square of the horizontal kick, without and with systematic resonance compensation ($Q_H+2Q_V = 8$).

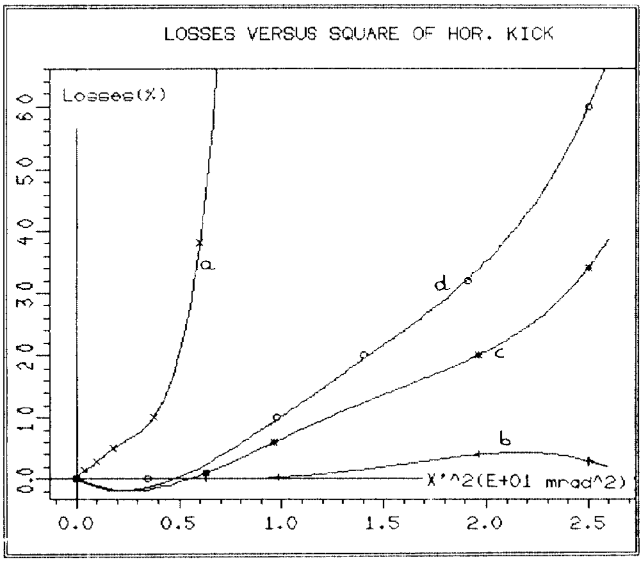

Fig. 6 - Losses function of the square of the horizontal kick, a) without compensation, b,c,d) with compensation, b) just after kick, c) after 1 min, d) after 5 min.

Conclusion

Sixty per cent of the LEAR machine was dismantled and rebuilt to accommodate the PFW's together with additional beam monitoring devices, renewed bakeout jackets and various modifications, within the shutdown period of 3 months.

A successful achievement for which the following people are largely to be thanked: R. Billinge, P. Lefèvre, D. Möhl for their constant support; P. Bossard for meaningful help during studies and construction; J. Chevallier, M. Duret, C. Lacroix, B. Moine for their high motivation during the shutdown, and L.Petty, J.M.Roux for the design of forming jigs and mould.

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