THE MODIFIED DAFNE WIGGLERS

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Abstract

Modifications to the pole shape of a spare wiggler have been tested to increase the width of the good field region, with the aim of reducing the effect of nonlinearities affecting the dynamic aperture and the beam-beam interaction. Additional plates have been machined in several shapes and glued on the poles. Accurate measurements of the vertical field component on the horizontal symmetry plane of the magnet have been performed to find the best profile. The particle motion inside the measured field has been tracked to minimize the field integral on the trajectory, to determine the wiggler transfer matrix in both horizontal and vertical betatron oscillation planes and to estimate the amount of non linear contributions. All wigglers in the collider have been modified to the optimized pole shape. Measurements with beam performed with the modified wigglers show a significant reduction of non-linearities.

INTRODUCTION

Each ring of the DAFNE collider [1] is equipped with 4 wigglers. The main parameters of the wiggler are given in Table 1 and a picture of the magnet is shown in Fig. 1. The wigglers are a strong source of non-linearity in the rings and their effects on the beam dynamics are extensively described in [2]: we recall here that the main effect on the beam is a quadratic dependence of the betatron tunes on the beam position in the wiggler, generated by an effective octupole component created by a decapole term in the wiggler field not centered on the wiggling trajectory of the beam inside the magnet.

In order to correct this non-linear term, a new spare wiggler has been purchased from the same builder of the wigglers installed on the collider. The magnet has been realized on the same design and with the same materials. We adopted the strategy of reshaping the pole faces by adding machined iron plates directly glued on the poles.

Table 1: Main wiggler parameters

Beam energy (MeV)	510
Nominal field (T)	1.8
Number of full poles	5
Number of terminal poles	2
Pole width (cm)	14
Pole length (cm)	21
Gap (cm)	4.0

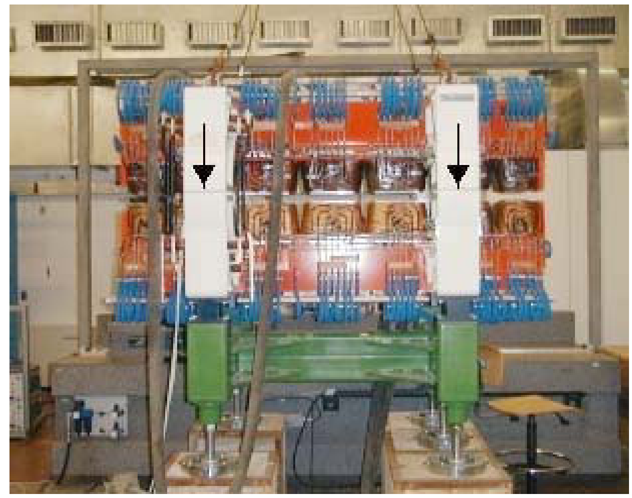

Figure 1: The spare wiggler in the magnetic measurement hall.

The effect of a (2k+2)-pole term on the beam dynamics can be expressed as

$$K_k = \frac{1}{B\rho}\int \frac{\partial^k B(z,x)}{\partial x^k} dz \qquad (1)$$

where the derivatives are calculated not on the wiggler axis, but along the wiggling trajectory of the beam. In terms of the derivatives calculated along the wiggler axis, indicated here with a suffix "0", the third order term is:

$$K_3 = \frac{1}{B\rho}\left[\int (\frac{\partial^3 B}{\partial x^3})_0 dz + \int (\frac{\partial^4 B}{\partial x^4})_0 x(z) dz + \cdots\right] \qquad (2)$$

The value of K_3, obtained from the measurements described in [2] on the original wiggler is of the order is $\approx$-8 10^2 m^{-3} and is mainly due to the second term in the square bracket in (2).

POLE SHAPING

In order to add the machined iron plates to the wiggler yoke, keeping the gap at the same value, the two halves of the magnet can be displaced by adding suitable spacers in the middle of the white C-shaped supports shown with black arrows in Fig. 1. This modification lengthens the magnetic circuit slightly reducing the peak field at the same gap value.

The vertical field component at the center pole and in the terminal ones has been measured on the original wiggler without any modification. Then, the two halves of the wiggler have been separated by means of 28 mm thick separators and the 14 mm thick iron plates glued on the poles without any modification of their shape. The peak field in this configuration is reduced by 6%.

The plates have been modified by modulating their thickness as a function of the distance from the wiggler axis, roughly following the criterion of keeping constant the resulting gap divided by the intensity of the field measured at the pole center on the original wiggler. The shape of the modified pole is shown in Fig. 2.

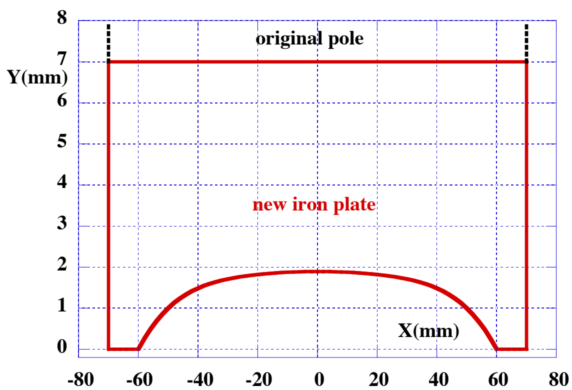

Figure 2 – Section of the shaped iron plate glued on the wiggler pole (horizontal and vertical sizes not in scale).

Due to the larger gap at the pole center, the peak field was further reduced by 5%, bringing the overall reduction with respect to the original wiggler to 11%, which would affect too much the damping effect on the beam. A first decision was taken to reduce the gap from 40 to 37 mm, still compatible with the vacuum chamber. The measured gain in peak field was 3%, still not enough for the beam dynamics. The final configuration was therefore obtained by reducing the maximum thickness of the plates from 14 to 7 mm, with a separator thickness of 11 mm, keeping the gap at 37 mm. The peak field is only 4% smaller than in the original wiggler. The dependence of the field at the longitudinal symmetry point of the magnet is shown in Fig. 3. The beneficial effect of pole shaping on field flatness is evident.

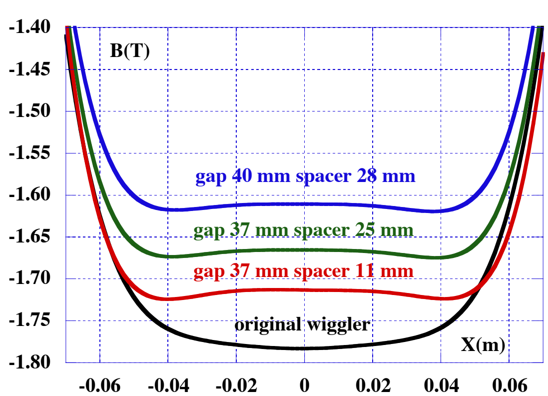

Figure 3: Vertical field component at wiggler center versus distance from longitudinal symmetry axis.

A second modification of the wiggler field comes from the requirement of a localized sextupole field at one of the terminal poles, which makes chromaticity correction in the collider easy due to the high dispersion and excellent beta functions separation at this position. Fig. 4 shows the shape of the additional iron plate at one of the two terminal poles.

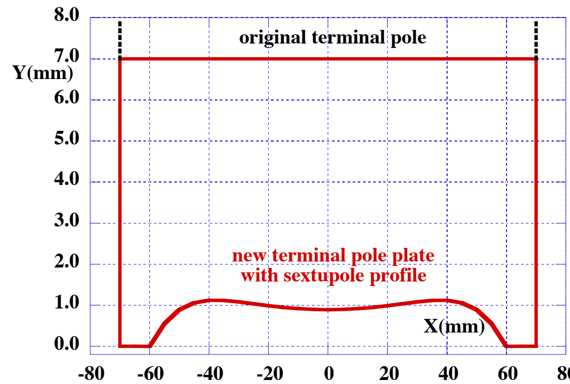

Figure 4: Section of the shaped iron plate glued on the terminal pole (horizontal and vertical sizes not in scale).

RESULTS

In order to evaluate the effect of the field modification on the non linear term (2), the field has been measured on the horizontal symmetry plane in a mesh of 4920 points, 328 longitudinal positions spaced by 8.35 mm and 15 horizontal positions spaced by 10 mm.

The measurements at the same longitudinal positions have been fitted with a fourth order polynomial and the fourth order term of the fit yielding the major contribution to the octupole term (2) is shown in Fig. 5 as a function of the longitudinal position around the central pole. The new profile reduces the fourth order non linearity by more than a factor two.

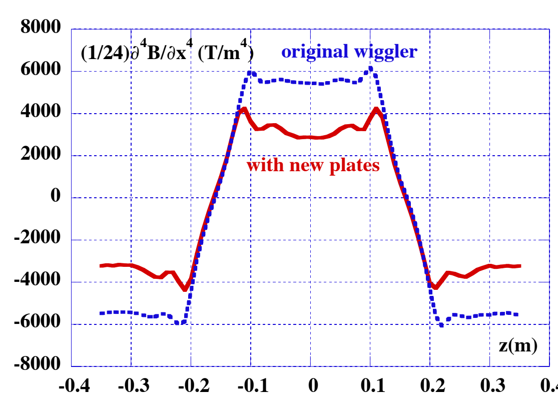

Figure 5: Fourth order term of the transverse fit in the central pole.

The second order term of the same fit in the terminal pole with the sextupole profile of Fig. 4 is shown in Fig. 6, compared to the same quantity in the original wiggler. The corresponding value of K_2 changes from 2.0 m^{-2} to 4.3 m^{-2}.

By interpolating the measured points, the trajectory of a test particle can be calculated both in the horizontal and vertical planes, making it possible to evaluate the full transfer matrix of the wiggler [3] and to estimate K_3. Fig. 7 shows the trajectories in the horizontal symmetry plane of two test particles, both starting from outside the wiggler at a distance of 11.8 mm from the wiggler axis, which is the geometry adopted in DAFNE to fully exploit the good field region of the wiggler. One of the two particles enters the wiggler from the terminal pole modified to enhance the sextupole contribution, the second from the other one. Both trajectories are parallel to the wiggler axis at the end of the wiggler, with a slight displacement (≈1 mm) with respect to the initial position due to the asymmetry in the field introduced by the terminal pole modification.

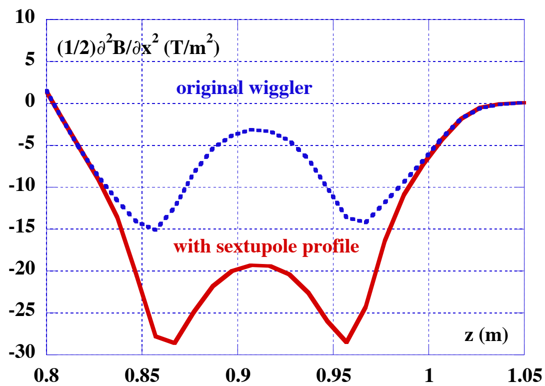

Figure 6: Second order term of the transverse fit in the terminal pole

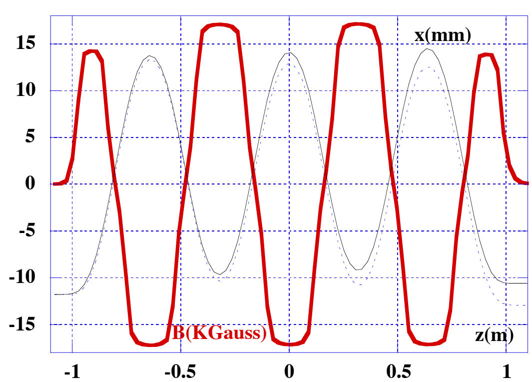

Figure 7: Trajectories in the horizontal symmetry plane of two particles; full line = starting from modified terminal, dotted line = starting from normal one. The field on axis is shown for reference.

By integrating the product of the fourth order term of the transverse fit in Fig. 5 times the horizontal trajectory of the beam it is now possible to calculate the third order contribution to the motion defined in (2), where the contribution of the third order term of the field in the wiggler is negligible due to the symmetry of the magnet with respect to its longitudinal axis. K_3 has been reduced to -3.5 10^2 m^{-3}, more than a factor 2 with respect to the original wigglers.

All DAFNE wigglers have been modified to the final configuration during the shutdown for the installation of the FINUDA experiment during summer 2003 [4]. More details can be found in [5].

BEAM MEASUREMENTS

This result has been checked with the beam by measuring the tune shift as a function of localized orbit bumps in the wigglers [6], with the same procedure described in [2]. Of course, the additional sextupole term in the terminal pole is now the dominant contribution, making the measurement of the quadratic behaviour more critical. Fig. 8 shows the result of the measurement for two wigglers in the electron ring (empty dots) and in the positron one (full dots). The average value for K_3 comes out to be (3.2±0.9) 10^2 m^{-3}, in good agreement with the predictions from the magnetic measurements. The averaged sextupole term is K_2 = (3.7±1.7) m^{-2} to be compared to the value of 4.3 m^{-2} quoted in the preceding section.

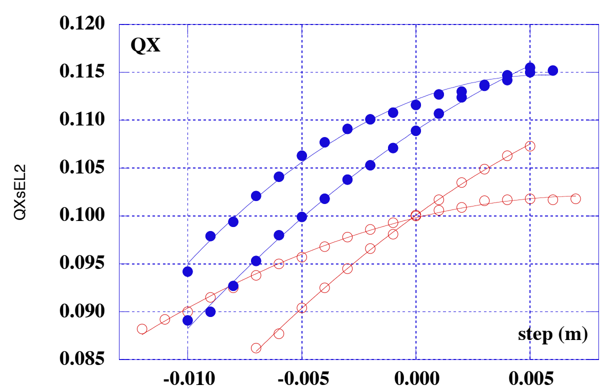

Figure 8: Measured horizontal betatron tune versus beam displacement in 4 wigglers

CONCLUSIONS

The shape of the poles in the DAFNE wigglers has been modified to enlarge the good field region and to reduce the octupolar contribution to the beam dynamics. A reduction larger than a factor 2 has been obtained and confirmed by measurements with beam after wiggler modification.

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