MULTIPOLES MINIMIZATION IN THE DAFNE WIGGLERS

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Abstract

The wigglers of the DAFNE main rings have been one of the major sources of the non-linearities in the collider at Frascati. A method to minimize the odd integrated multipoles around the beam trajectory (the even ones tend to vanish due to the periodicity of the magnet) has been developed and already described. After a study, including both multipolar and tracking analysis has been performed to determine the optimal configuration, the DAFNE wigglers have been modified accordingly. The results of the simulations have been validated by field map measurements.

INTRODUCTION

The eight normal conducting wigglers used in the DAFNE main rings to reduce the damping times have been source of non-linearities in the machine since their installation in the 90's. The large excursion of the beam trajectory from the axis (about ±1.3 cm), combined with the field roll-off (these magnets are close to saturation to produce the necessary peak field in the mid-plane), make these effects quite strong for DAFNE. In particular in fall 2000 tune shift measurements by means of closed orbit bumps around the wiggler evidenced a large integrated octupole [1]. The most successful intervention in the past, which allowed to reduce the integrated octupole by a factor 2.5, was the installation of pole shims to improve the transverse field uniformity [1].

To further reduce the non-linearities a different approach has been studied and optimized. After a brief recall to the method and the optimization on the DAFNE wigglers, the magnetic measurements are presented.

THE METHOD

The method and the optimization proposed to reduce the non-linearities has been already described elsewhere, so in this paper only a quick recall is given. A more detailed description of the approach and the optimization can be found in [2] and in [3] respectively.

The integrated multipoles with respect to the beam trajectory can be written as:

$$I_n \equiv \int_{Magnet} b_n^{\,T}\, ds \quad n = 0,1,2,... \qquad (1)$$

where b^T_n is the n^{th} (0 corresponds to the dipole, 1 to the quadrupole, …) order of the polynomial field expansion around the reference trajectory, x_{TR}, and s is the curvilinear coordinate. The odd integrals can be rewritten as a function of the polynomial field coefficients with respect to the wiggler axis $b^A_{f(j)}$ as:

$$I_{2j+1} = \int_{Magnet} (c_{2j+2}\, b^A_{\ 2j+2}\, x_{TR} + c_{2j+4}\, b^A_{\ 2j+4}\, x_{TR}^{\ 3} + ...)\, ds \qquad (2)$$

where $c_{f(j)}$ are some positive constants. If the magnetic and the geometric axis of the wiggler are disentangled by alternatively displacing the poles in such a way that the odd powers of x_{TR} change sign in each half-period in eq. (2), the contributions to the integrals coming from the regions inside the poles can be compensated with those from the regions between the poles. The final effect is that a specific odd order integral vanishes and the other ones are reduced.

THE APPLICATION TO THE DAFNE WIGGLERS

Table 1 shows the operational specification of the DAFNE wigglers. The nominal current of the central coils has been 693 A since the beginning of their operation to produce the target 1.7 T peak field in the mid-plane. After the DAFNE upgrade in 2007, it has been decided to run the wiggler at a lower current, accepting a smaller peak field, to save electrical power consumption.

Table 1: DAFNE Wiggler Specifications. The Nominal Currents used before the DAFNE Upgrade are also Indicated in Parentheses.

	Central poles	**Terminal poles**
Number of poles	5	2
Nominal current (A)	550 (693)	390 (564)
Pole width (cm)	14	
Period (cm)	64	
Gap (cm)	3.7	

The optimal shift of the axis (±7.3 mm), which allows to cancel the integrated octupole and to strongly reduce the higher order integrated multipoles has been determined by means of both tracking and multipolar analysis on several 3D magnetic models of the DAFNE wiggler [3]. These models have been optimized both at 550 A and 450 A, which, in the shifted poles configuration, allows to maintain the peak field larger than 1.6 T thanks to the removal of the pole shims and the consequent shortening of the magnetic circuit. To validate the results of the simulations the wigglers have been modified accordingly and the 2D maps of the vertical component of the magnetic field on the mid-plane, B_y, have been measured and compared with the simulations. All the maps have been measured by a system of two Hall probes controlled by a Labview code developed at the Frascati lab. at 10 mm steps in the transverse (x) and 8.35 mm in the longitudinal direction (z), along the entire magnetic length of the wiggler.

In the next subsections the comparison between the simulations and the measurements of the several configurations are presented.

The 550 A configuration

The first measurement has been done on a spare wiggler modified by shifting the poles with respect to the geometric axis of the magnet, as shown in figure 1, according to [3].

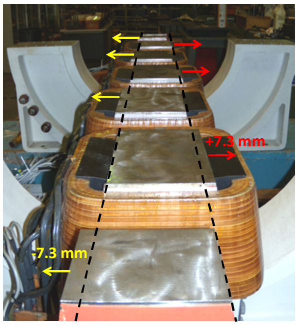

Figure 1: Bottom half of the wiggler during the modification process.

The comparison between the simulations and the measurements is shown in both figures 2 and 3, where B_y as a function of z along the geometric axis of the wiggler (x = 0 m) and B_y as a function of x at the centre of the wiggler (z = 0 m) are respectively reported.

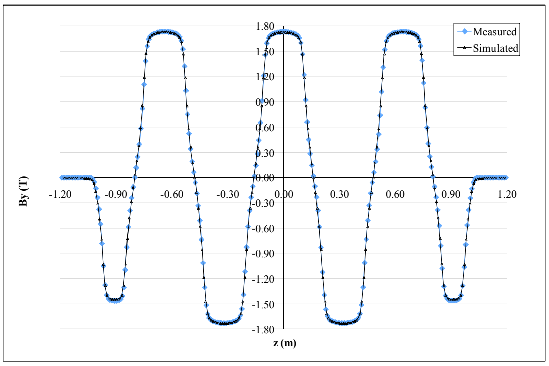

Figure 2: Measured and simulated B_y along the wiggler geometric axis (x = 0 m).

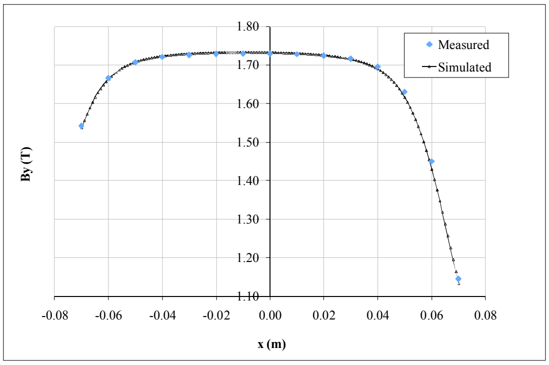

Figure 3: Measured and simulated B_y as a function of the horizontal transverse coordinate at the longitudinal centre of the wiggler (z = 0 m).

The excellent agreement (maximum discrepancy less than 0.2%), confirms the multipolar and the tracking studies.

Another big advantage of the shifted pole configuration is that the shims are no more necessary. They can be therefore removed and, consequently, the length of the magnetic circuit is reduced by 2.2 cm [1]. Thanks to this the peak field on the beam at 550 A is slightly larger than that in the configuration with the shims at 693 A, as shown in figure 4. This permitted to reduce the electrical power consumption by about 30%.

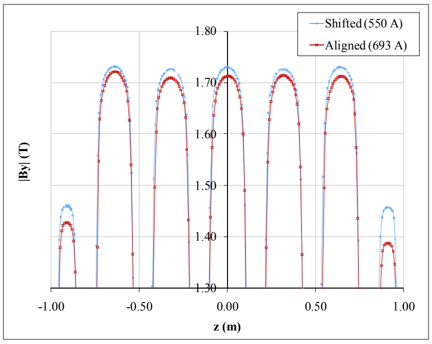

Figure 4: B_y absolute value along z (measurements). The asymmetry in the 693 A configuration is due to a sextupole shaped shim on one of the terminal poles [1].

The 450 A configuration

The tracking studies have been repeated at 450 A to verify the effect of lowering the current on the method. The exit angle of the beam trajectory versus the x shift at the entrance of the wiggler for several axis displacements is shown in figure 5.

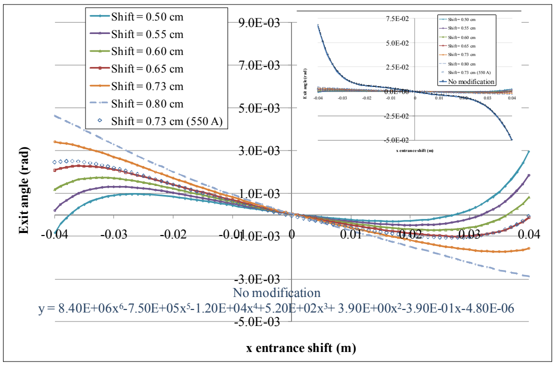

Figure 5: Exit angle as a function of the displacement at the entrance of the wiggler for several axis displacements and the case of the wiggler without the modification.

The difference was not dramatic, especially if compared with the wiggler without the modification, but in any case the optimization process has been repeated also at this current. In this case with a ±8 mm displacement the non-linearities were further reduced. All the wigglers of the main rings are being therefore modified accordingly during this shut down.

Optimization of the terminal coils

In the 450 A configuration the condition of cancelling the first integral along the wiggler axis, proportional to the exit angle of the reference trajectory, is that the current of the terminal coils is ≈80% of that of the central windings. Since each coil is divided into 5 independent windings, it is possible to approximately satisfy this condition by short-circuiting one of them in the terminal coils and powering the entire wiggler with the same power supply with a significant electrical consumption reduction.

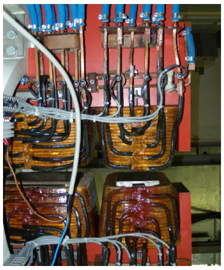

Figure 6: Coils connections in the DAFNE wiggler. From the right to the left the terminal and the central coils.

Figure 7 shows the field integral along z when switching off one winding at a time in the terminal poles.

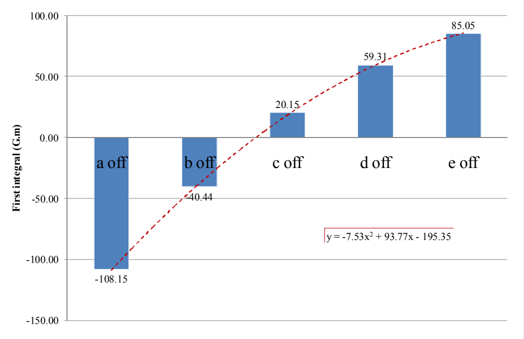

Figure 7: Field first integral along z. All the coils are in series and one winding in the terminal coils is off (simulations). The closest one to the mid-plane is a, b the second one, ...

A possibility would be to switch off c and to use two correctors to compensate the residual integral (half of their nominal current would be enough).

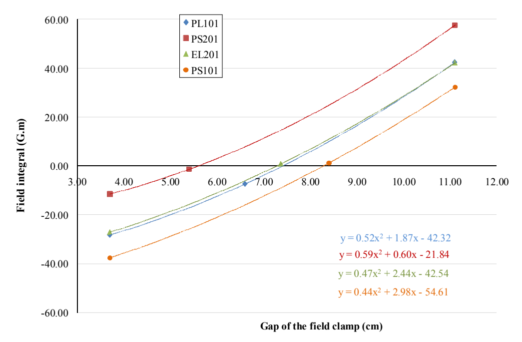

Figure 8: First integral along z versus the gap of the field clamp (measurements).

A more convenient way is to switch off b and to compensate the residual negative integral (see also figure 2) by increasing the gap between the field clamps, as shown in figure 8. In this way the field integral is corrected for each wiggler at the order of 1 G.m.

The final configuration

During this shut down the wigglers of the DAFNE main rings have been modified with the ±8 mm shift, putting in series all the coils, switching off the b windings in the terminal windings and adjusting the gap in the field clamp to correct the residual field integral. Figure 9 shows the plot analogous to that of figure 5 calculated from the measured maps.

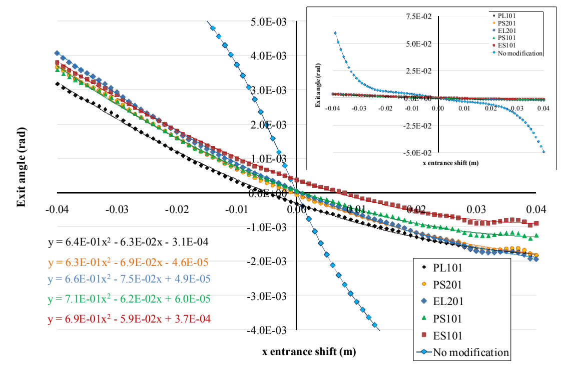

Figure 9: Exit angle versus the shift at the entrance of the wigglers measured up to now. The case of the wiggler without the modification is also shown.

A 2nd order polynomial fit ($\langle K^{sext}_{MAD} \rangle = 1.34 \pm 0.06\ \mathrm{m}^{-2}$) is enough to fit all these curves with randomly distributed residuals, indicating that the higher order multipolar terms are cancelled by this method.

CONCLUSIONS

A method to minimize the odd order non-linearities which affect the DAFNE main rings wiggler has been optimized on 3D models of the magnets. The simulations have been confirmed by the magnetic measurements on the wigglers modified accordingly. The power consumption has been also strongly reduced by removing the pole shims no more necessary thanks to the new method applied and by putting the terminal coils in series with the central ones. In the final configuration the tracking studies on the measured maps indicate that the non-linearities are almost cancelled. All the wigglers in DAFNE are being modified accordingly and measurements on the beam will be done at the next DAFNE start up this year.

REFERENCES

[1] A. Battisti et al., "The modified wiggler of the DAFNE main rings", DAFNE note MM-34 (2004).

[2] S. Bettoni, "Reduction of the integrated odd multipoles in periodic magnets", Phys. Rev. ST-AB, 10, 042401 (2007).

[3] S. Bettoni, S. Guiducci, M. Preger, P. Raimondi, C. Sanelli, "Reduction of the non-linearities in the DAFNE main rings wigglers", PAC07 Proceedings and EuroTeV report 2007-051 (2007).