BEAM BASED MEASUREMENTS WITH THE MODIFIED WIGGLERS IN DAFNE

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Abstract

A novel idea to minimize the odd high order non-linearities in periodic magnets has been presented in other articles in the past. The optimization of this method on the wigglers of the main rings in DAFNE has been performed by means of multipolar and tracking analysis. After the magnetic measurements on a spare wiggler confirmed the accuracy of the magnetic model used for the optimization, all the insertion devices in the main rings have been modified accordingly. In fall last year tune variation measurements as a function of the closed orbit bumps amplitude around the wigglers confirmed the validity of the proposed technique. In this paper these beam based measurements are presented.

INTRODUCTION

In circular machines wigglers are usually installed to reduce the damping time of the rings. These kinds of magnets, which generate magnetic field where the particles undergo oscillations also of the order of centimetres, are often source of non-linearities. Because of the periodicity of these devices the terms which add up in each magnet and along the ring are the odd terms in the US notation (quadrupole, octupole, …) of the field expansion around the beam reference trajectory, whereas the even ones are in perfect periodic magnets compensated.

Several approaches can be considered to mitigate this effect. A possibility is to correct a specific integrated odd order by adding some jaws at the extremities of the device [1]. This approach can be applied to only a specific order and if the correction is small enough. Another possible scheme is to mitigate the field roll-off by adding pole shims. This approach may only reduce the integral but only in the region of the poles, and therefore is not well applicable to short poles wigglers.

A novel approach, based on the minimization of the integrated odd multipoles in each semi-period of the magnet, has been studied and applied to the DAFNE main rings wigglers.

THE METHOD

The technique has been already discussed elsewhere [2], [3], then in this proceeding only the basic concept useful to understand the approach will be briefly described.

The approach is based on the fact that the terms b_k^T of the multipolar expansion around the beam reference trajectory x^T can be written as a function of the ones with respect to the magnetic axis b_k^A as:

$$b_k^T = \sum_{j=1}^{\infty} c_{k+j-1} b_{k+j-1}^A \left(x - x^T\right)^{j-1} \quad (1)$$

where c_j are positive constants and x is the horizontal dimension. In particular an even term can be written as:

$$b_2^T = c_2 b_2^A + c_3 b_3^A \left(x - x^T\right) + c_4 b_4^A \left(x - x^T\right)^2 + \ldots \quad (2)$$

and an odd one as:

$$b_3^T = c_3 b_3^A + c_4 b_4^A \left(x - x^T\right) + c_5 b_5^A \left(x - x^T\right)^2 + \ldots \quad (3)$$

The integral of each term of the right side of eq. (2) is null in each period, because of the left-right symmetry of the magnet and the fact that the even multipolar terms with respect to the axis change sign from a pole to the following one. In eq. (3) this compensation is not valid anymore, because both the odd power of the beam trajectory and the even terms of the expansion around the axis change sign from a pole to the following one.

In the novel approach the magnetic and the geometric axes are disentangled, in such a way that in each semi-period of the magnet (where the even terms with respect to the axis have a constant sign) the beam trajectory changes sign. With this method is therefore possible to cancel a specific integrated multipolar odd order and reduce the other ones without affecting the even ones.

THE DAFNE MAIN RINGS WIGGLERS

In the main rings of DAFNE four wigglers per ring have been installed. The most important parameters of these devices are reported in Table 1.

Table 1: Parameters of the DAFNE Main Wigglers

	Central poles	**Terminal poles**
Number of poles	5	2
Nominal current (A)	550	390
Peak field (T)	1.73	1.41
Pole width (cm)	14	
Period (cm)	64	
Gap (cm)	3.7	
Turns/coil	80	
Conductor size (cm)	0.7 (square)	

The beams excursion in the field generated by the DAFNE wigglers reaches almost 1.3 cm amplitude, because of the relatively low beam energy (510 MeV) and the large magnetic peak field. Due to this the DAFNE wigglers were source of strong non-linearities for the rings, in particular a non acceptable integrated octupolar term has been found. Several approaches have been tried in the past to reduce this effect, and the most successful one was to install pole shims schematically shown in Fig. 1 to mitigate the field roll-off. The integrated octupole has been reduced by a factor 2.5 by means of this intervention, but it was not negligible yet and the peak field has been reduced by about 15%, because of the increase of the field gap.

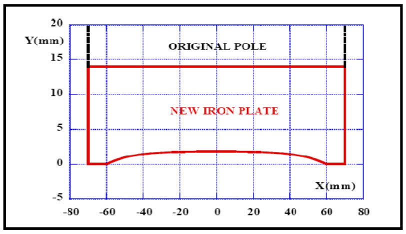

Figure 1: Sketch of the modified wiggler to improve the transverse field uniformity [4].

Several ways are possible to implement the novel approach: by means of shims, by cutting the poles or by shifting them. The first possibility has been discharged because it would imply an increment of the gap and it could be strongly dependent on the wiggler current. The second one has been described in details in [2] and the latter one in [3]. The shifted poles solution has been preferred because it's the one with the smallest field roll-off, allows having more field than the other one, like shown in Fig.2, and is almost zero cost implementation.

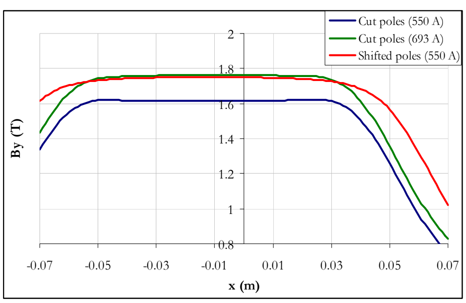

Figure 2: Comparison of the simulated vertical component of B at the centre of the wiggler. The peak field of the shifted configuration at 550 A produces the same field of the cut poles solution with almost 700 A current.

The solution has been studied and improved in these years at several currents. During this optimization it has been also decided to put the terminal coils in series with the central ones by switching off one slice in the final windings [3]. All these interventions optimized in the simulations as well directly on a spare wiggler allows going from 2460 kW* to 740 kW power consumption for the total eight wigglers, corresponding to about 1.2 M euros/year saved money in Italy considering 200 days of operation/year.

The picture of the modified wigglers is shown in Fig. 3.

*The calculation is done considering the wiggler current in the central coils at the very beginning of the operation and at the latest running condition at 400 A in all the windings. If we keep the same field (550 A vs 693 A) the gain would be slightly greater than a factor 2.

The solution has been optimized at several currents and for all of them tracking and multipolar analysis indicated that the method is able to strongly reduce the non-linearities [6].

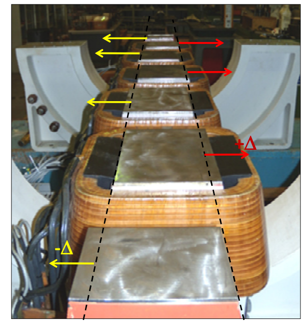

Figure 3: Half wiggler after the modification [6].

The tune shift measurements

After the spare wiggler has been modified accordingly to the optimized configuration, the same modification has been implemented on all the wigglers in the main rings. The 2D field maps measured were at the per mille level in agreement with the predictions [6]. With such an agreement the tracking analysis done using these field maps as input gave almost a perfect cancellation of the integrated high order non-linearities [6].

To further investigate the result of the method at the end of last year we did tune shift measurements as a function of the amplitude of closed orbit bumps around the wigglers. This kind of measurement is one of the most accurate to quantify the non-linearities, because in a ring the beam passes typically at least some ten thousand times in the magnet region and therefore also very small non-linearities are measurable.

From the measured tune shift variation, ΔQ_x, the integrated non-linear terms in the MAD sense, i.e. defined as:

$$K_i^{MAD} \equiv \frac{1}{B\rho}\frac{\partial^i B_y}{\partial x^i} \tag{4}$$

can be deduced from the relation:

$$\Delta Q_x = K_2^{MAD} \cdot \frac{\beta_x}{4\pi} \cdot \Delta x + K_3^{MAD} \cdot \frac{\beta_x}{8\pi} \cdot \Delta x^2 + \ldots \tag{5}$$

where β_x is the betatron oscillation function. In eq. (5) the first order term on the right side refers to a sextupole, the second order to an octupole, … with respect to the beam trajectory.

The closed orbit bumps are done by using the two correctors in front and the two behind a wiggler to have enough knobs to control x and the angle at the same time. The strengths of the correctors are calculated by the optics model.

As a preliminary step we measured the response of the beam position monitors (BPM) inside the bumps around the wigglers and we used the fit of the response to correct our readings. The ring length is changed by the bump, then for each step in x the frequency of the RF has to be adjusted to stay on the closed orbit. Before doing the bumps we then measured the frequency correction we have to apply to correct for this effect.

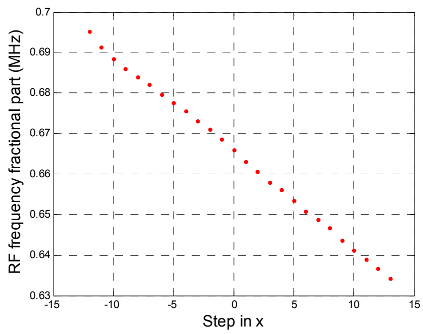

Figure 4: Fractional part of the RF frequency as a function of the measurement index used to correct the ring length.

The first beam based measurement has been performed in fall November last year and it gave the experimental beam based demonstration that the proposed method works. As is shown in Fig. 6, in fact, the measured tune shift is a linear function of the bump amplitude, which, according to eq. (5), excludes the presence of any order higher than the sextupole (appreciable with the precision of this measurement). In Fig. 5 the measurements performed before the modification has been implemented [4], clearly showing an integrated octupole, is also shown for comparison.

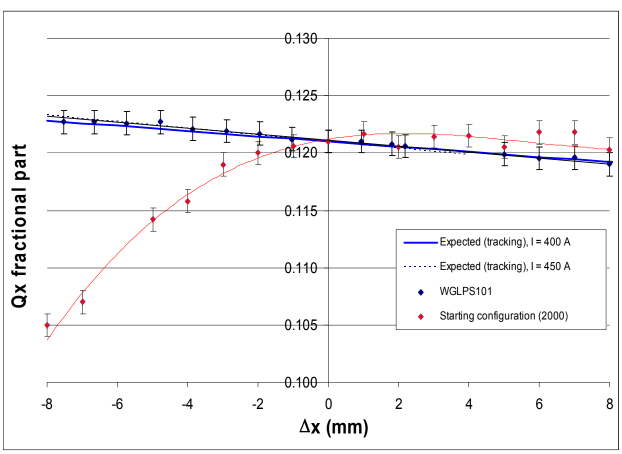

Figure 5: Measured tune shift as a function of the closed orbit bumps before (starting configuration) and after the modification. The predictions from the tracking analysis are also reported.

In Fig. 5 the very nice agreement with the expectations is also shown. The straight lines which are plotted, in fact, are not fit of the measured points, but they are calculated from the tracking simulations. The predicted tune shift is determined from the tracking curve we computed using the field maps measured for each wiggler, shown in Fig. 6.

In particular the 2nd order coefficient of the fit of the angle at the exit as a function of the closed orbit bump amplitude, given by:

$$a_2 \equiv \frac{1}{B\rho}\frac{1}{2!}\int_{Wiggler}\frac{\partial^2 B_y}{\partial x^2}\,ds \qquad (6)$$

is used to compute K_2^{MAD}. Substituting it in eq. (5) we calculate the slope of the tune shift shown in Fig.5.

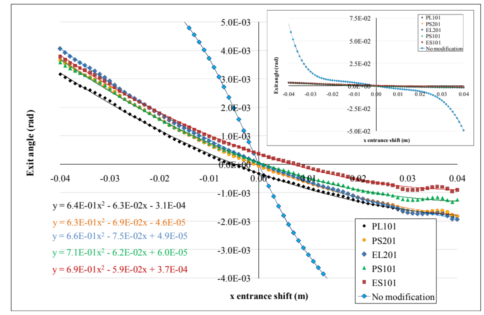

Figure 6: Simulated angle exit as a function of the bump amplitude using the measured maps as input [6].

After this other measurements have been done on other wigglers. The range of the bump amplitude has been further increased up to ±10.5 mm by reconnecting the water cooling of the correctors used for the bump. Also in this range the measured integrated octupole was negligible [7].

CONCLUSIONS

A novel approach to reduce the non-linearities in periodic magnets has been proposed and optimized by means of tracking and multipolar analysis for the DAFNE main rings wigglers in the last years. After that magnetic measurement confirmed the validity of the models, all the wigglers in the machine have been modified accordingly. At the end of last year tune shift measurements have experimentally demonstrated the validity of the approach. Furthermore the measured tune shift was in very good agreement with the expected one calculated from the tracking curves determined by using the 2D measured field maps as input. This method, at zero cost if implemented in the design phase, allows strongly reducing the non-linearities in DAFNE and it can be in principle applied to any other wiggler.

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