DYNAMIC MULTIPOLE SHIMMING OF THE APPLE UNDULATOR UE112

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Abstract

The dynamic multipoles of the BESSY APPLE undulator UE112 have successfully been shimmed for the elliptical mode using Fe-shims. In the inclined mode the multipoles have to be minimized actively. This can be accomplished either with an array of flat current wires or with rotating permanent magnets. Both methods are compared with respect to accuracy, flexibility and complexity. For both strategies the dynamic properties of the device have been studied in tracking simulations which are based on a generating function formalism using an analytic description of the undulator and the shim field integrals.

INTRODUCTION

The high field (1.0T) and the long period length (112mm) of the BESSY UE112 APPLE in combination with the medium electron energy of 1.7GeV give rise to strong dynamic multipoles [1] of up to 3 Tmm. They reduce the dynamic aperture and the beam lifetime significantly if they are not compensated. The strength and the structure of the multipoles change with gap and phase of the undulator and the shimming strategies have to be adopted accordingly. Passive shimming is always the preferred solution but for the inclined mode not applicable. We discuss the passive and active shimming strategies for the UE112 operated in elliptical and inclined mode and present the impact on the electron beam dynamics as derived from tracking simulations.

ELLIPTICAL MODE

In the elliptical mode the dynamic multipoles can be compensated with L-shaped Fe shims as proposed by J. Chavanne et al. [2]. The transverse shape of the shims has been optimized at the phase of λ/2 such that the minimum of the first multipoles coincides at one specific shim strength (Fig. 1). The horizontal and vertical sizes have been chosen as free parameters.

Based on simulations L-shims have been applied to the device before installation in the ring. Two in-situ iterations have been performed in order to fine tune the shim strength within 15%. The optimization has been done in the vertical linear mode where the measured dynamic horizontal aperture has been used as a figure of merit [3].

The quality of the compensation varies with the row phases. In particular at row phases of 0.0λ and 0.375λ the residual multipoles are larger (Fig. 2). In principle it is possible to vary the shim strength S and shim length L (longitudinal direction) to achieve a better averaged compensation for all phases (Fig. 2). This is however complicated and not necessary for the specific case of the UE112 since an additional active compensation scheme will be applied for this device.

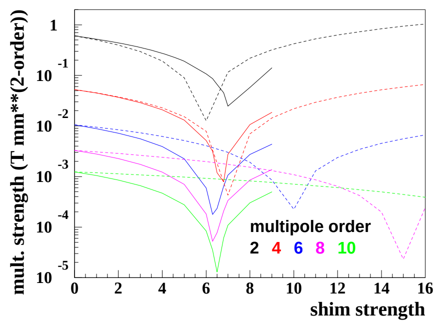

Figure 1: Comparison of the multipole content of residuals after shimming for two shim types with different transverse shape. Solid: horizontal / vertical = 2mm / 4mm. Dashed: horizontal / vertical = 4mm / 4mm. Shim strength = 1 corresponds to 4 shims, one on each row, with a thickness of 0.2mm and a length of λ/2.

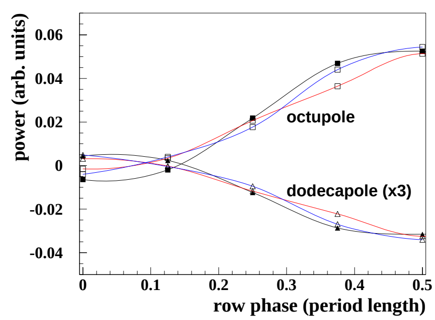

Figure 2: Dynamic multipoles (black) and shims. The shims have equal thickness and length (red) and varying parameters (blue), respectively. Shim parameters: red: L=λ/2 and $S=1$, blue: L= λ/8, λ/4, 3λ/8, λ/2 and S=0.2, -3.3, 5.8, -2.0.

INCLINED MODE

Active Shimming Schemes

In the inclined mode the horizontal dynamic field integrals are reduced but not cancelled by the L-shims which are optimized for phase = λ/2. The vertical field integrals are enhanced. Tracking simulations as well as experimental studies show that the dynamic field integrals in the inclined mode have to be compensated.

A passive compensation as presented for the elliptical mode is not available for the inclined mode. Two active compensation schemes are possible: i) rotating permanent magnet blocks at the ends of the device, ii) parallel current wires distributed over the whole length of the device.

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The permanent magnets can be adapted to the multipole characteristics via a variation of the diameter in the transverse direction (Fig. 3, [4]). When changing the phase the strength can be adjusted by rotating the magnets. Using four instead of two magnets at one undulator end magnet slices of equal size can be adopted which gives more flexibility during the optimization of the shim pattern (Fig. 4). Furthermore, no longitudinal fields are generated on axis and an electron beam displacement is avoided. Generally, permanent magnets have the disadvantage that they are optimized for a very specific case and the shim pattern can not be adjusted in-situ.

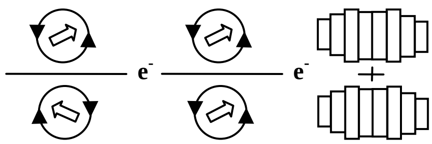

Figure 3: Two rotating permanent magnets at the undulator ends. In “zero kick” position (all arrows are parallel) the electron beam still sees the magnets. Left: the beam is displaced. Middle: a longitudinal field is generated.

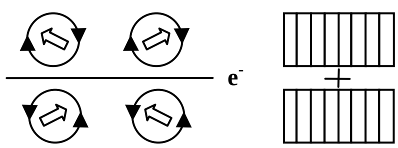

Figure 4: Four rotating magnets at the undulator ends.

The second method has been proposed by I. Blomqvist [5]. It is based on several parallel current wires which are driven by individual power supplies (Fig. 5). This option provides full flexibility for all operation modes. Residual field integrals as plotted in Fig. 2 can easily be compensated. The disadvantage is a slightly larger gap (0.8mm for the UE112) which is, however, not harmful for long period devices and short period devices do not need an active compensation at all.

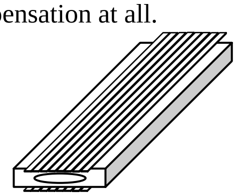

Figure 5: Schematic view of a vacuum chamber equipped with an array of parallel wires. For the UE112 totally 28 current strips driven by 14 power supplies will be used.

Tracking Simulations

The beam dynamics for both shimming options have been studied using analytical expressions for the undulator fields and shim field integrals in a generating function algorithm [6]. In [6] the tracking simulations have been done for the symmetric cases of phase = 0mm and λ/2. Recently, the code has been extended to be used for any row phase. Thus, we have a completely parametrized, analytical tracking routine of an APPLE undulator for all gaps and phases. For details of the field description and the generating function approach see [6].

In the elliptical mode the vertical field integrals of the shims can be described in the midplane via a series of sine functions whereas the horizontal field integrals are zero. In the inclined mode cosine terms show up as well and the horizontal field integrals in the midplane are generally non zero. With x (y) being the horizontal (vertical) coordinate the shim field integrals have the form:

$$\tilde{B}_x = \sum_{i=1}^{n}\left[c_i \cdot \sin(k_i x)\cdot \cosh(k_i y) + s_i \cdot \cos(k_i x)\cdot \sinh(k_i y)\right]\cdot E_i$$

$$\tilde{B}_y = \sum_{i=1}^{n}\left[-c_i \cdot \cos(k_i x)\cdot \sinh(k_i y) + s_i \cdot \sin(k_i x)\cdot \cosh(k_i y)\right]\cdot E_i \qquad (1)$$

$$k_i = 2\pi \cdot i/\lambda_1$$

$$E_i = \exp\left(-k_i \Delta g/2\right)$$

The Fourier coefficients of Eq. 1 are derived from horizontal and vertical field integrals evaluated in the midplane. 30 coefficients are sufficient to describe the field integrals of the L-shims and the additional active shims within the vertical physical aperture of ±8mm. L-shims, rotating magnets and current wires are treated in the same formalism.

The distortion of the horizontal phase space of the unshimmed UE112 in the inclined mode (Fig. 6) demonstrates clearly the need for an active compensation.

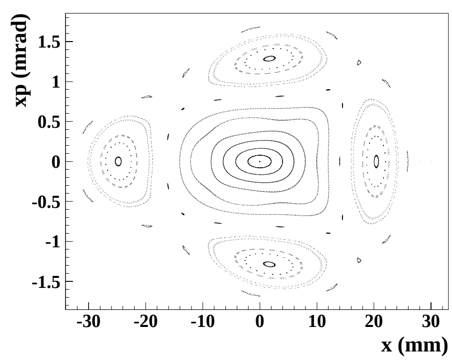

Figure 6: Horizontal phase space of the unshimmed UE112 in the inclined mode (phase = λ/4). Only L-shims are applied.

An ideal shim configuration is defined such that the dynamic field integrals in the midplane (y = 0) are perfectly compensated. An ideal shim is generated to serve as a reference in the tracking simulations. The Fourier expansion coefficients of the ideal shim are derived from the negative dynamic field integral distribution. Fractions of the ideal shim kicks are applied after each period.

In the midplane the compensation is perfect for the ideal shim and still very good for the wire shim (Fig. 7). Off axis phase space distortions show up, because the dynamic field integrals have a different off axis behaviour than the static field integrals of the shims. These differences are, however, less important due to the small vertical betatron function of the BESSY ring of 4.5 m.

Real shims have a discrete structure (4mm grid for the UE112) and are not always continuously distributed over the undulator length (e.g. rotating magnets). Fig. 8 shows the residual horizontal and vertical kicks for the ideal shim and various real shims. The initial coordinates are distributed on a horizontal phase space ellipse with β_x=10m, α_x=0, x_{max}=0.02m, y=0mm and yp=0mm. The performance of the wire shim is close to the ideal shim. Rotating magnet shims at both undulator ends are worse by more than one order of magnitude. The residuals for magnets located at only one undulator end are even larger. Distributing the magnet shim pattern continuously over the undulator length (which is not possible in reality) reduces the residuals significantly. Hence, the key point is the distribution of the compensating shims rather than the shim pattern itself. In this respect the wire shims have a clear advantage versus the rotating magnets. Current wires will be applied to the UE112 in the near future.

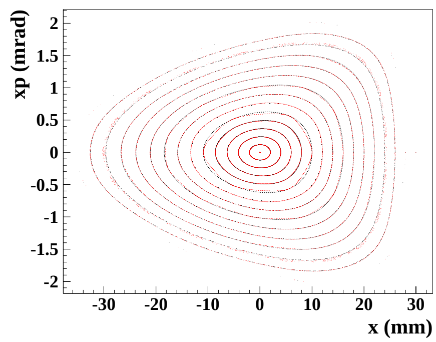

Figure 7: Horizontal phase space without the UE112 (black) and with current wire shims (red).

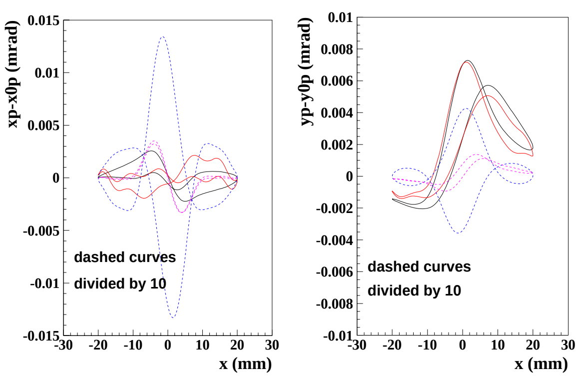

Figure 8: Residual horizontal (left) and vertical (right) kicks for the ideal shim (black), the wire shims (red) and the rotating magnet shims (dashed). The rotating magnets have been placed at one undulator end only (blue) and at both ends (magenta), respectively.

The relevant resonances for the beam dynamic can be studied in detail in so called frequency maps. Frequency maps are graphs which correlated certain parts of the phase space to the tune space. Frequency maps can be generated either from tracking simulations [7] or from turn to turn bunch position measurements [8, 9].

Tracking results for the dynamic aperture for the inclined mode (phase = $\lambda/4$) with two different shimming schemes are shown in Fig. 9 in the range of interest for $|x| < 26$mm and $|y| < 6$mm, in comparison with the bare lattice. The figure shows the initial coordinates of tracked particles, surviving at least 1024 turns. It shows clearly a reduction of the dynamic aperture for the rotating magnets whereas the current wire case is acceptable.

The coordinates of these tracking calculations have been frequency analyzed to generate a frequency map (Fig. 10). Working point and sextupole strength are taken from the nominal optics. Obviously, the shimming with current wires generates less distortions than the shimming with rotating magnets.

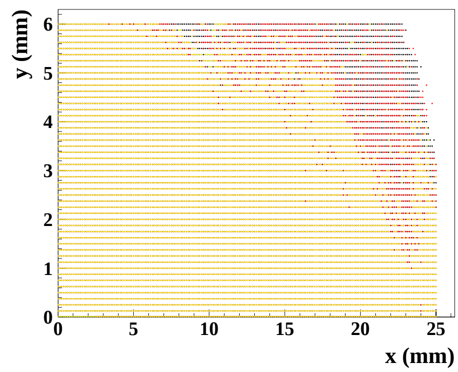

Figure 9: Dynamic aperture for the bare lattice (black), the wire shims (red) and the magnet shims (yellow).

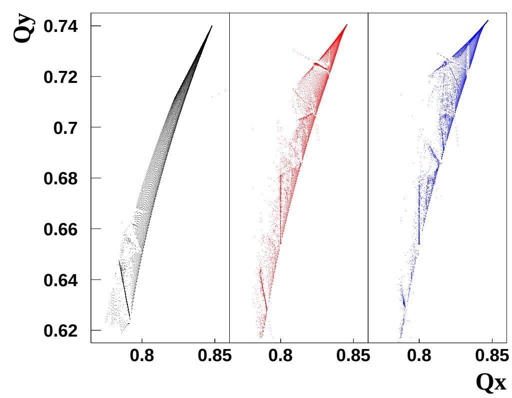

Figure 10: Frequency maps for the bare lattice (left), for the current wires (center) and for the rotating magnets (right).

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