ORIGIN OF SHIFT DEPENDENT MULTIPOLES IN APPLE-II UNDULATORS

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Abstract

APPLE-II insertion devices are very flexible devices for production of variably polarized photons. This devices inherently suffer from shift dependent integrated field multipoles that can reach values which can seriously deteriorate quality of the electron beam. Since there is no really effective shimming method for correction of this errors, it is important to understand where they originate. Paper presents a study of integrated field multipoles shift dependency based on deformation of magnetic array due to magnetic forces. We have modeled separately deformations of each magnet keeper in the magnetic array. Model calculations have shown that most of integrated field multipole dependency on the shift is due to mechanical deformation in combination with magnetic effects.

INTRODUCTION

Insertion device should have minimal influence on the electron beam in all modes of operation, consequently requiring a tight control of the integrated magnetic field over the length of the device. Both second and first field integrals should be as close to zero as possible in all operational modes. Also the field integrals mutipoles should be as low as possible and should change as little between different operational modes.

For this reason a lot of design effort was put in the magnetic structure, specifically on the end field terminations [1]. But all this efforts do not solve all the possible errors. It has been shown in multiple cases [2, 3, 4] that mechanical deformations play a critical role in the performance of this devices. Most notably shift dependent multipoles have been observed in the EPUs for FEL-1 and FEL-2 line at FERMI@Elettra [5, 6] and also at other light sources [2]. For these reasons a study of the origin of shift dependent multipoles was prompted.

Even in ideal case it is not possible to keep all the multipoles at zero at all operational modes of an APPLE-II insertion device. Normal dipole is generated in the symmetric field device by default and changes with the shift due to the non zero permeability of magnetic material. Sextupole and its change is also generated by the non zero permeability of the magnetic material. It is possible to limit this changes by proper design of the end field terminations [1].

On the other hand it is not possible to generate the quadrupoles both normal and skew in ideal device. Hence it is believed that they arise for the mechanical deformations. For example a rotation of the horizontally magnetized block around vertical axis [4] can give a rise to a skew quadrupole, which is the most notably observed shift dependent multipole [2, 5, 6]. In the 55 mm periods EPUs for FEL-1 for FERMI@Elettra a large shift dependent skew quadrupole was observed. Largest change of about 400 G was observed at minimum 10 mm gap. Values of multipoles decrease with increasing gap.

To understand which deformations will generate different multipoles and how they change with shift, it is necessary to make a model that includes also deformations for the ideal structure. Following paragraphs contain description and results from such a model.

MAGNETIC MODEL WITH STRUCTURAL DEFORMATIONS DUE TO MAGNETIC FORCES

In order to study how mechanical deformation influence the magnetic performance of the insertion device a special RADIA code was developed without any symmetries allowing a movement and rotation of each magnet block. This code generates an APPLE-II magnetic structure and applies deformations to the structure by displacement and rotation of each block. It is possible to either enter deformations from external files, produced by the mechanical Finite Element Analysis (FEA) of the mechanical structure or the code can also calculate simplified deformations due to magnetic forces.

Magnetic forces

First part of the code will calculate magnetic forces and torques on each magnet block, hence giving an input for the FEA mechanical calculations. For this calculation permeability of material was not taken into account since it does not effect the forces significantly. The largest force is exerted in vertical direction for both horizontally and vertically magnetized block. This force is mostly due to the neighbors in the array. Horizontal and transverse force change with the shift due to the changing neighbors.

At the moment no available computer is able to compute a complete mechanical structure applying forces on each magnet separately. So it is necessary to apply some assumptions. Hence a series of steps were studied in order to get a complete picture. By applying only the deformations from frame and girders no change in multipoles is observed. From this it can be concluded that the multipoles must have an origin in different displacement of each magnet block.

Since FEA can not calculate deformation in a complete mechanical structure for each block separately a approximation approach was taken. Magnetic forces and torques on each magnet were calculated and from this an isotropic

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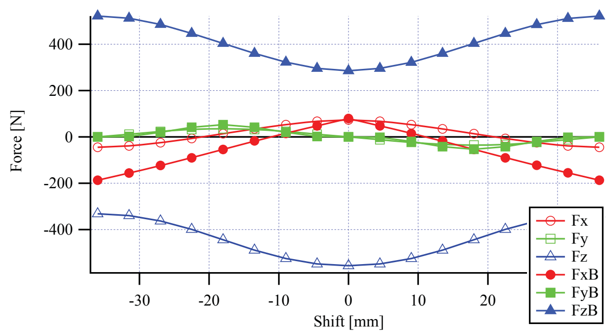

Figure 1: Calculated change of forces with the shift in a vertically and horizontally polarized magnetic block.

deformation, translation and rotation, was calculated by simple multiplication of deformation coefficient. Figure 2 show a small model with deformed structure, deformations are exaggerated 100x. For each configuration of gap/shift a new calculation of forces is required, therefore very long calculations are required to achieve a clear picture.

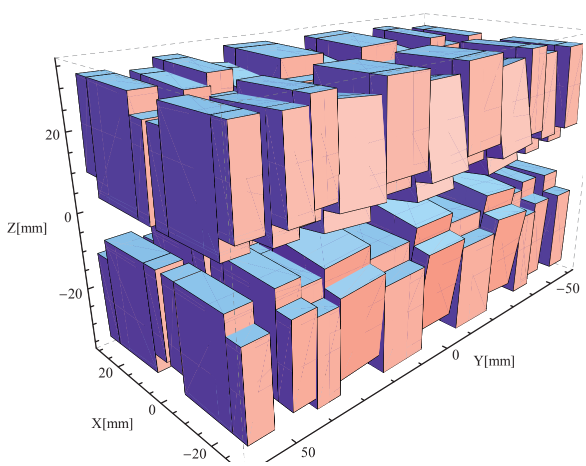

Figure 2: Short 3D model of a deformed APPLE-II magnetic structure. Deformation are amplified 100 x for clarity.

Non deformed case

First let us examine a non deformed case. Figure 3 shows the transverse change of normal and skew field integrals are minimum gap and shift of 10 mm. As it can be seen there is no change in the skew field integral. If we look at the shift dependency of integrated multipoles we see that only vertical dipole and sextupole change with the shift. This is due to non unit permeability of magnetic material. We must note here that it is not possible to generate quadrupoles in a non deformed APPLE-II magnetic structure.
To understand whether multipoles are generated in the end field termination or are cumulative through the magnetic structure we need to look at the change of multipoles with increasing number of periods. Only very small changes in

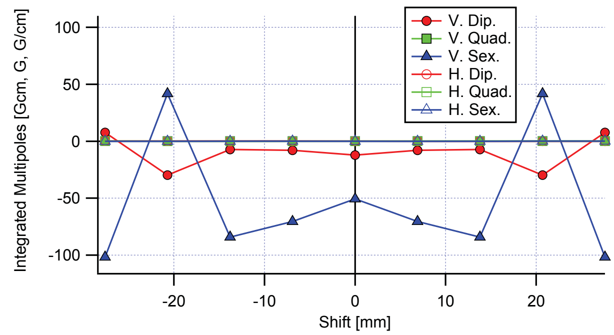

Figure 3: Calculated shift dependency of integrated multipoles for non deformed magnetic structure. Dipole and sextupole changes are due to non zero magnetic permeability of magnetic blocks. Quadrupoles can not be generated in such a structure.

the integrated multipoles are observed so we can conclude that integrated multipoles are generated in the end field termination and are not cumulative trough the magnetic structure. Here we keep in mind that this is only valid for our model where deformations are isotropic and only due to magnetic forces.

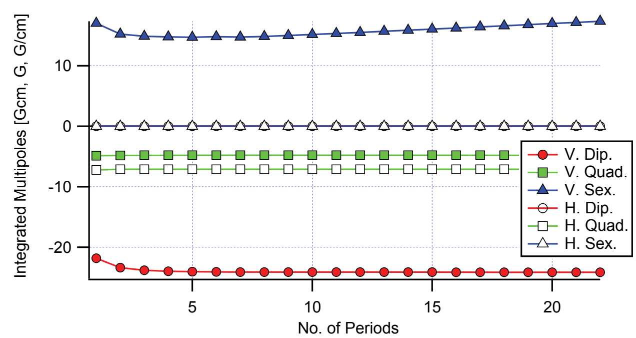

Figure 4: Calculated change of integrated multipoles with number of periods. It is evident that multipoles are mostly generated in the end field section and in close proximity to them.

Deformed case

A detailed study of influences of displacement in different directions and rotations around different axes has shown that only rotation round longitudinal axis can generate a significant skew quadrupole. On the other hand sextupole, specifically normal sextupole can be generated almost in all cases of translations and rotations. From this we can conclude that most important contribution to quadrupole generation is from rotation around longitudinal axis. Again this only applies for isotropic deformation from magnetic forces only and when deformations are applied to all magnetic blocks in a structure. As noted before also rotation around vertical axis of the longitudinally magnetized block generate a skew quadrupole behavior, but this is only true if we do not rotate all the blocks in the magnetic

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structure.

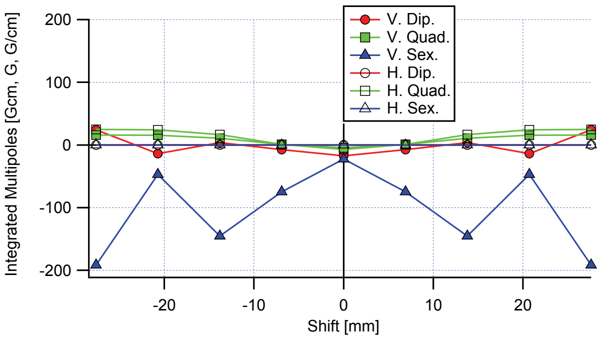

Figure 5: Calculated shift dependency of integrated multipoles on a deformed model. Quadrupoles are generated by rotation around longitudinal axis.

Attempts to reproduce the shift dependency of skew quadrupole as measured in the FERMI undulators have failed, as it is apparently not possible to reproduce such an error by applying translations and rotations according to magnetic forces and torques on single magnets only. Magnet displacements (translations and rotations) along different degrees of freedom will not occur with the same deformation constants, since they are held by a holder that breaks the symmetry. For a reproducible description of the shift dependency a detailed finite element analysis (FEA) of magnet deformations and their application to the entire magnetic structure is needed.
However measurements of an EPU for Pohang Light Source II (PLS2), which has different improved mechanical design of a magnet holder, give much better accordance with the model. Figure 6 shows comparison of a change of integrated skew quadrupole with the shift change for a model magnetic structure and measurements of a 70 mm period EPU for PLS2. We can see that in this case the model describes well the behavior of integrated skew quadrupole.

CONCLUSIONS

We have presented a model of APPLE-II device that includes deformation of magnetic structure due to magnetic forces. As it can be seen in some cases where deformations can be described as isotropic and only due to magnetic forces, we get good results when comparing simulation and real measurements. But when deformations are not isotropic we need to do real FEA modeling of complete magnetic structure applying appropriate forces on each magnet block. At the moment such calculation is beyond capability of a normal personal computer and we have to apply some simplifications. Such a model with anisotropic deformations is currently under development.

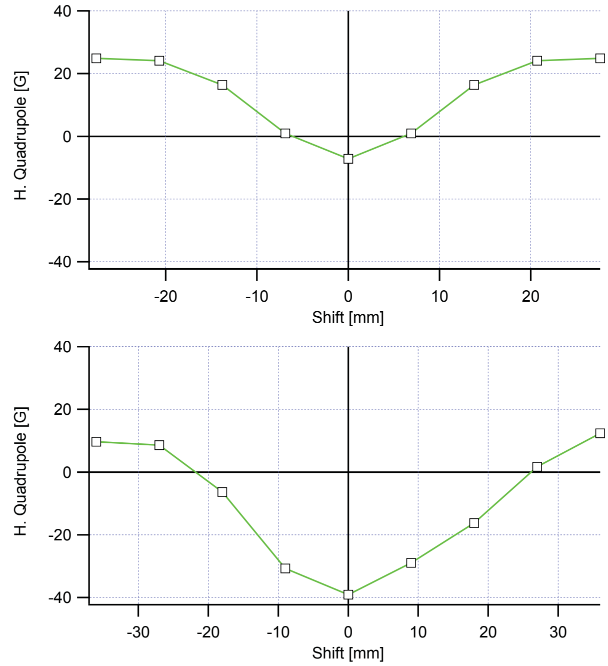

Figure 6: Comparion of shift dependency of skew quadrupole in a measured (right) 70 mm period EPU and model calculation (left). We see that we can at least qualitatively predict the behavior of quadrupoles. Calculation is only valid for and isotropic deformations due to magnetic forces.

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