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STUDY OF ROW PHASE DEPENDENT SKEW QUADRUPOLE FIELDS IN APPLE-II TYPE EPUs AT THE ALS*

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Abstract

Since about 5 years, Apple-II type Elliptically Polarizing Undulators (EPU) have been used very successfully at the ALS to generate high brightness photon beams with arbitrary polarization. However, both EPUs installed so far cause significant changes of the vertical beamsize, especially when the row phase is changed to change the polarization of the photons emitted. Detailed measurements indicate this is caused by a row phase dependent skew quadrupole term in the EPUs. Magnetic measurements revealed the same effect for the third EPU to be installed later this year. All measurements to identify and quantify the effect with beam will be presented, as well as some results of magnetic bench measurements and numeric field simulations.

INTRODUCTION

Apple-II type EPUs at the ALS [1] have been successfully in operation for 5 years. These undulators are pure permanent magnet devices and the first 3 ALS devices have a period length of 5 cm and a length of 1.85 m. They provide full polarization control [2].

Similar to all the other undulators at the ALS the users have complete freedom to change the gap of the EPUs to produce photons of different energies. In addition the users are allowed to shift two opposing quadrants (Q1 and Q3 in Fig. 1) longitudinally for control of the polarization.

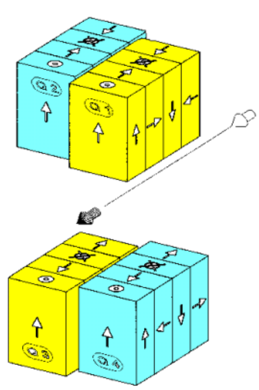

Figure 1: Arrangement of the permanent magnet blocks for the EPU at the ALS.

In order to make optimum use of the limited insertion straight space available at the ALS, the EPUs occupy only half a straight and are built into a chicane arrangement which separates the beam axes from the two half straights by more than 2 mrad. In order to allow a maximum number of independent experiments, polarization switching is performed by mechanically changing the row phase of the undulator, in contrast to the concept used at BESSY II and other places, where polarization changes are realized by optical chopping which switches between the light coming from two EPUs. To reduce systematic errors resulting from the polarization switching, the EPUs at the ALS provide the capability to change the row phase fairly fast. The minimum time to change from left to right circular polarization is about 1.6 s.

Like all insertion devices, EPUs have systematic and random field errors, which have an adverse effect on the beam, that can depend both on gap and row phase of the device. The main categories of field errors relevant for the performance of the ALS are:

1. Variation of on axis field integrals with EPU phase (causing orbit distortions).
2. Variations of the (mostly vertical) beamsize (both with gap and with phase):
   (a) Due to focusing changes (systematic focusing terms from the bulk of the undulator).
   (b) Due to coupling terms (skew quadrupole like or solenoid like). This effect seems to be the dominating one for the vertical beamsize variations at the moment and has been a problem for many other beamlines.
3. Higher order effects impacting the dynamic (or momentum) aperture, for example due to the feld roll-off, which is quite significant and systematic in circular polarization mode.

ON-AXIS FIELD INTEGRAL VARIATION

The end terminations of the ALS EPUs were originally designed to be steering and displacement free. For zero row phase, this design goal was indeed achieved, however, due to the small difference of the magnetic permeability of the permanent magnet material and the anisotropy (parallel vs. perpendicular to the magnetization direction) there is a fairly significant residual on-axis field integral for row phases different from zero. In case of the ALS, the symmetry of the device causes these effects to produce mostly horizontal field integrals, i.e. fields causing vertical closed orbit distortions. The magnitude is several 100 G-cm and the dependence on the row phase is sine-like. This effect was identified early (during magnetic measurements before the installation of the first device). It agrees very well with calculations for our EPU geometry and material properties, conducted later using the RADIA [3] code. To remedy the effect, a fast (200 Hz) feedforward system was installed [4],

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using two high bandwidth corrector magnets in each plane, placed right next to the EPUs. A feed forward algorithm was developed using two dimensional tables (see Fig. 2). Using the fast feed forward, the orbit distortion due to the EPU switching polarization at full velocity at minimum gap can be reduced from several 100 μm down to a few μm outside the EPU straight. In addition, a new chicane design was developed, combining a variable strength permanent magnet dipole with fast, hysteresis free correction air-coils [5]. With this new design, the correction of the orbit distortion could be accomplished more locally, minimizing the systematic orbit shift for the EPU beamline itself.

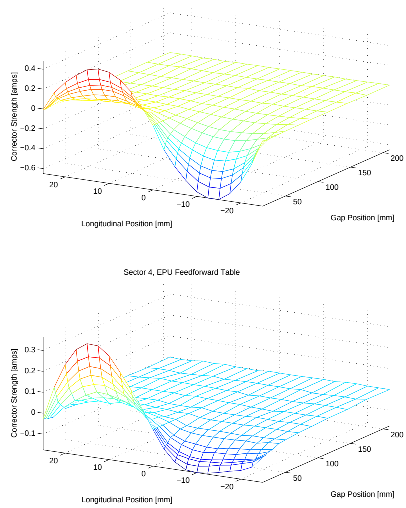

Figure 2: Two dimensional feed forward table used for orbit compensation of one of the EPUs (2 of the 4 correctors used are plotted).

Subsequently, a fast orbit feedback system has been installed and commissioned at the ALS [6]. Using the feed forward together with the fast feedback, no residual influence on the orbit larger than the BPM noise floor can be detected.

FOCUSING EFFECTS

In addition to the steering effect of on-axis field integrals, all undulators can have a dependence of their field integrals on transverse position, or other effects causing focusing or higher order distortions to the beam. At the ALS, the systematic focusing of all planar undulators and wigglers has been corrected for several years using lattice quadrupoles in a feed-forward scheme. This scheme corrects both the tune and the beta beating caused by the planar undulators and improved the vertical beamsize stability at the ALS significantly. However, for several reasons the focusing effects of the EPUs are more important. The first reason is that the shift parameter is frequently changed to change the polarization. This causes a distortion in the field integrals of about the same size as changing another undulator from fully open to fully closed. In addition the horizontal beta function in the insertion device straights is about 5 times as large as the vertical one. Therefore the horizontal tuneshift from the EPU is very significant (see Fig. 3). The effect

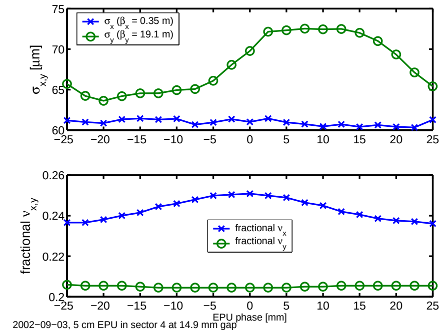

Figure 3: Change in tune and beam size due to longitudinal EPU motion (1.9 GeV, 14.9 mm gap, 3% coupling).

can be computed quantitatively with a model of the ideal device using the RADIA code.

Because the possible speed of shift parameter changes is fairly high, making slow corrections using the normal lattice quadrupoles originally was very difficult. With the advances in computer and network speed and with the new fast orbit feedback system at the ALS, it finally became feasible to compensate for the quickly changing tuneshift of EPUs as well. Systems using either a local quadrupole compensation coil embedded in grooves in the vacuum chamber of the EPUs or regular storage ring quadrupoles have been tested. They both work well and the orbit distortion caused by the quadrupole changes are minimized down to the BPM noise floor by the fast orbit feedback.

However, as one can see in Fig. 3, the change in vertical beamsize in most cases does not have the same qualitative behaviour as the tune change. This became especially true after the ALS lattice was switched from an artifical excitation of the coupling resonance to increase the vertical emittance and therefore the Touschek lifetime, to a scheme where a vertical dispersion wave is used instead. In this case, the sensitivity of the vertical beamsize to moderate tune changes is basically zero.

INTEGRATED SKEW GRADIENTS

To understand the shape and magnitude of the vertical beamsize variation, many measurements with beam and later also with the third EPU on the measurement bench were carried out. All indirect effects (due to orbit, misalignment of the whole device, etc.) were eliminated in the studies and the final result was, that a fairly sizeable integrated skew quadrupole gradient must be present in the devices themselves, which depends on the row phase. Precision measurements of the row phase and gap dependence of the effect were carried out using orbit response matrix analysis. This analysis allows a very precise determination of small gradient and skew gradient errors and is used routinely for lattice diagnostics at other light sources as well. Fig. 4 shows the measured dependence of the integrated skew gradient of the two EPUs installed in the ALS at that time. The skew gradients are rather large (more than 100 G-cm/cm) and the dependence on row phase is similar

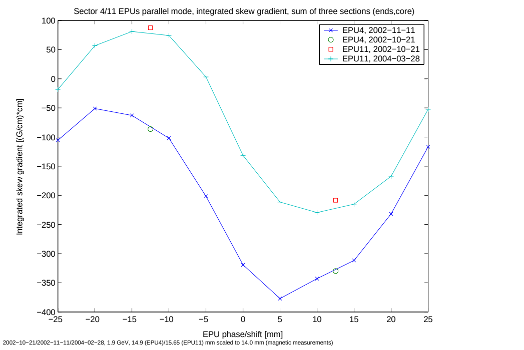

Figure 4: Integrated skew gradient as a function of shift parameter for the 2 EPUs installed in the ALS. For each position an orbit response matrix was taken and analyzed.

for both devices. Reproducability of the values at different dates has been very good.

In parallel, measurements were carried out with the third EPU on a magnetic measurement bench. They confirmed a row phase dependant integrated skew gradient of similar magnitude and phase dependance as the beam based measurements showed for the first two devices. However, all attempts to find the reason for this effect using magnetic or mechanical measurements as well as simulations using RADIA have not been successful. In the simulations magnetic errors could easily produce sizeable skew quadrupole terms, but they all had very little row phase dependence.

To reduce the significant impact the EPU related variations of the vertical beamsize have on experiments at the ALS, an active feedforward system was tested on top of other measures, which passively made the sensitivity of the beam size to the fixed size skew quadrupole terms smaller over the last years. Unfortunately, the skew quadrupoles of the ALS are rather inefficient, since they are installed in the arcs, where beta function ratio and horizontal dispersion are very different from the straights where the EPUs are installed. Therefore the feedforward uses four wires which are installed in grooves of the EPU vacuum chamber along the full length of the EPU. It allows generation of an integrated skew gradient of about 1.5 times the needed magnitude for a truly local correction. Fig. 5 shows the results of the initial tests. At small baseline coupling (amplifying the effect of the EPU), the coil is capable of nearly perfectly compensating the skew gradient effect on the beamsize, using a predictive feed forward table based on the orbit response matrix analysis mentioned in the previous section. With the larger nominal ALS emittance (for Touschek lifetime reasons), the relative variation is even smaller. A complete feedforward algorithm has been implemented this spring and is being used for one of the devices in routine user operation since the beginning of June.

HIGHER MULTIPOLES

Higher order fields in insertion devices can impact the dynamic (or momentum) aperture, for example due to the feld roll-off, which for an EPU is quite significant and sys-

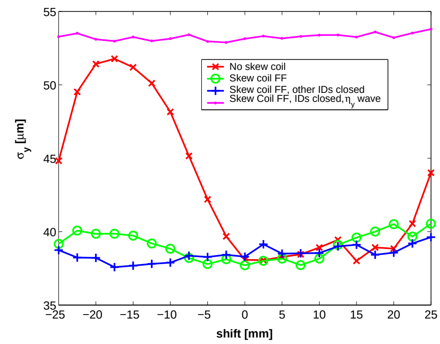

Figure 5: Local compensation via a skew quadrupole coil.

tematic in circular polarization mode. The effects were studied measuring detuning with amplitude and complete frequency maps for horizontal and circular polarization modes. The nonlinear effects in those cases are very small and have not been a problem with the cm period devices so far. However, new lower photon energy beamlines at the ALS requiring longer period EPUs are under construction (Merlin beamline). So we have started to study the effects in tracking simulations and are also planning to conduct more precise measurements with the devices already installed.

SUMMARY

The EPUs at the ALS have been operated very successfully, producing good scientific results. However, they did create significant impact on the beam stability. The main effects were on-axis field integrals, focusing, and a row phase dependent skew gradient. All effects were studied in detail and compensation schemes and improvements to the passive sensitivity of the lattice are in place, successfully minimizing the negative effects to the sensitivity level of our beamize and orbit monitoring systems.

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