FIELD CORRECTION FOR A ONE-METER LONG PERMANENT-MAGNET WIGGLER*

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Abstract

Field errors in wigglers are usually measured and corrected on-axis only, thus ignoring field error gradients. We find that gradient scale lengths are of the same order as electron beam size and therefore can be important. We report measurements of wiggler field errors in three-dimensions and expansion of these errors out to first order (including two dipole and two quadrupole components). Conventional techniques for correcting on-axis errors (order zero) create new off-axis (first order) errors. We present a new approach to correcting wiggler fields out to first order. By correcting quadrupole errors in addition to the usual dipole correction, we minimize growth in electron beam size. Correction to first order yields better overlap between the electron and optical beams and should improve laser gain.

Introduction

This paper discusses the correction technique used on a recently assembled 1-meter long, 2.05-cm period, 4-mm-gap permanent magnet wiggler. The taut-wire technique was used to measure and correct the magnetic field to first order in three dimensions[1]. The wire was moved transversely in the x-y plane to examine two dimensions, with distance along the wire (or time during the signal) providing the z dimension.

The peak K value for this wiggler is 1.23, corresponding to a peak wiggle amplitude of 50 µm for a 40-MeV beam. The electron beam radius in the wiggler is 200-400 µm, whereas the optical beam radius is 600-700 µm for 3-µm light. To obtain good overlap between the electron beam and optical beam, we aim to have the average trajectory of an electron deviate from its initial position a distance less than a peak wiggle displacement. This criterion is perhaps overly conservative at 3-µm operation, but at shorter wavelengths typical of higher harmonic operation better magnetic field quality is needed.

Earlier Work

Hall probes are used for the majority of wiggler field measurements performed at institutions other than LANL. Because of the poor spatial resolution (≥1mm) of Hall probes, and the tedious nature of the measurement, only the average field on axis is ususally measured. Measurements are often made for only one component of the field, for which the wiggler field is the major term. Data is numerically integrated twice to yield the particle trajectory in the x-z plane (for B_{wiggle} in the y-direction). Results are of limited use because it is assumed that there are no transverse gradients to the magnetic field. In fact, electron beam size can be of the same order as gradient scale lengths; thus a measurement and subsequent correction of gradients is important. Field gradients are due to unwanted quadrupole fields that defocus the beam in one plane. This reduces overlap and thus gain.

Preston and Warren[2] published results using the taut-wire, in which they measured both transverse components, B_x and B_y, of the field along the x-axis. They discuss field errors in terms of unwanted vertically and horizontally polarized magnetic moments. Errors are indicated by changes to the slope of the signal envelope where the signal is proportional to the second integral of the field. Errors are canceled using small pieces of permanent magnet oriented vertically or horizontally at the approximate z-location of the error. An important point is that these correctors are, for convenience, applied to only one half of the wiggler.

Present Work

The measurements reported here are taken one step further. The wire is moved off axis on a ±1-mm by ±1-mm grid in 1-mm steps, yielding data for both B_x and B_y at nine transverse positions. The error fields are interpreted as the sum of a dipole error, obtained from the on-axis data, and a quadrupole error, obtained from the gradient of the error field. It became apparent during the correction process that positioning correctors on only one-half of the wiggler can cancel one type of error but, in the process, create a new error. For example, a vertically polarized corrector used to correct a dipole field error introduces a quadrupole error.

It is useful to introduce a Taylor series expansion of the wiggler field out to first order in order to categorize the types of errors and later to show how the wrong type of correctors couples these.

$$B_y = B_{wigg}\cos(kz) + B_{oy}(z) + Q_n(z) * x + Q_s(z) * y$$

$$B_x = B_{ox}(z) + Q_n(z) * y - Q_s(z) * x$$

All terms except $B_{wigg}\cos(kz)$ are error terms and correspond to non-periodic dipole, normal quadrupole, and skewed quadrupole type errors. Errors occur at discrete z-locations corresponding to "bad" permanent magnets. Figure 1a shows how a skewed quadrupole error is introduced by using a single corrector to correct a vertical dipole error. Conversely, correcting a skewed quadrupole will introduce a vertical dipole error. The long rectangles represent the permanent magnets of the wiggler where the error is located;

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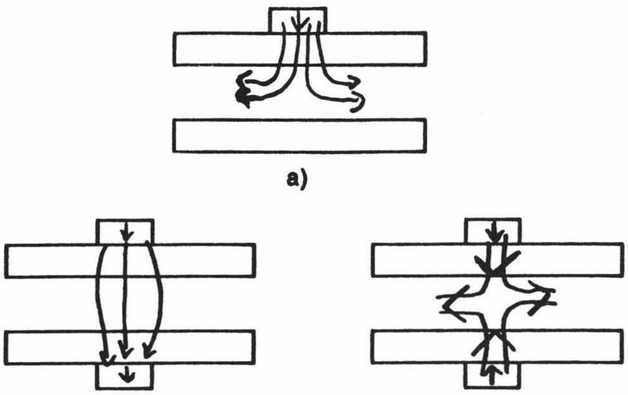
the small rectangle is the corrector with its field lines shown schematically. Figures 1b and 1c show how, by using correctors on both sides of the wiggler, the original error can be eliminated without introducing a new error (to first order).

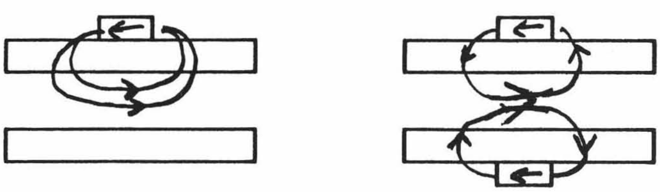


a)

b) c)

Fig. 1 (a) A single magnet used to correct vertical dipole (skewed quadrupole) causes a skewed quadrupole (vertical dipole) error; (b) a better way to correct a vertical dipole error; (c) a better way to correct a skewed quadrupole error.

Experimental data of this specific example is give in the next section. A second example is given in Fig. 2. A B_x dipole error is corrected in Fig. 2a using one horizontally polarized corrector; however, a normal quadrupole error is introduced. By using two-correctors, as shown in Fig. 2b, the dipole error is corrected without introducing the linear quadrupole error albeit a less important second order (sextupole) error is created. By reversing the direction of either the top or bottom magnet (Fig. 2b) a normal quadrupole is produced.



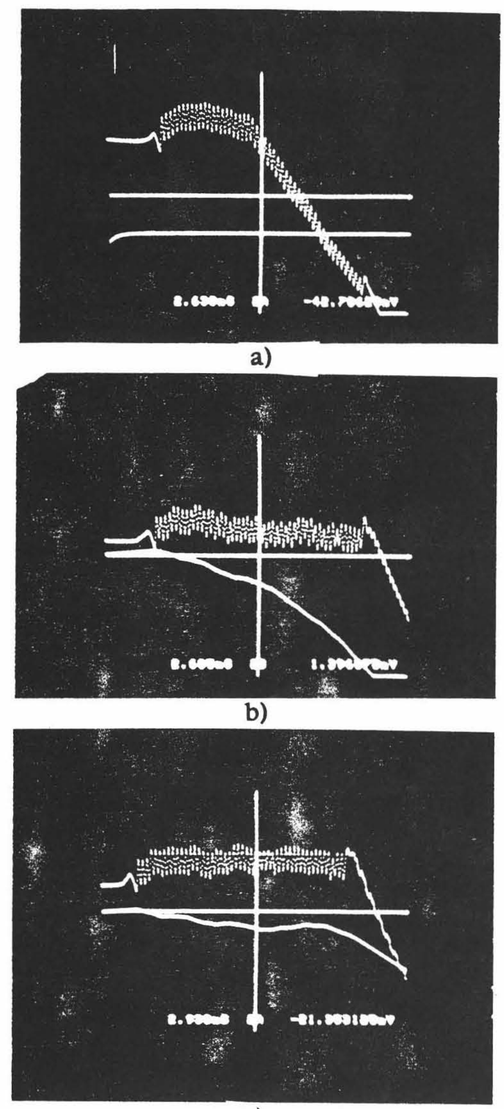
a) b)

Fig. 2 (a) Correcting a Bx dipole error with a single horizontally polarized corrector, introducing a normal quadrupole error; (b) a better way to correct the dipole error.

In conclusion, we find that, for correcting errors out to first order, symmetry must be maintained to avoid creating new errors in the process of correcting existing ones. Experience shows that ability to correct errors is limited by the number and variety (polarization, shape, and volume) of corrector magnets available.

Results

Signals for x motion of the wire (wiggle plane) and for y motion are referred to as the major and minor signals, respectively. All signals are the second integral of the field, proportional to the particle trajectory. The peak-to-peak amplitude of the sinusoid corresponds to 100 µm of electron beam displacement. Figure 3a shows data (major signal only) for the wire approximately centered on the wiggler geometric axis without any correctors. The signal is dominated by a large error, located almost halfway into the wiggler, which causes a "kick" and thus a linear deviation of the trajectory from the axis. After a few periods the centroid has moved a distance greater than one wiggle thus violating our criteria for field quality. Figure 3b shows the effect of using a relatively large vertically polarized corrector, on only one side of the wiggler, to correct the major signal; however, the minor signal is too large. Finally, an additional horizontally polarized corrector corrects the minor signal without affecting the major signal (Fig. 3c), as expected for the wire on axis. At this point the wiggler is corrected to order zero (i.e., ~~on~~ axis) except for the some adjustment needed at the very end of the wiggler.



a)

b)

c)

Fig. 3 Data with wire centered (a) major signal with no correctors; (b) major signal corrected with vertical corrector, minor signal too large; (c) minor and major signal corrected on-axis except for far end of wiggler.

Figure 4 shows major and minor signals along the x-axis at -1, 0, and +1 mm after the correction. The major signal is independent of x (the three major signals overlie each other) whereas the minor signal has an odd symmetry (indicative of a skewed quadrupole) where the large vertical corrector was placed to correct the major signal. This important effect is explained by the discussion in the previous section and Fig. 1. With correctors added to both sides of the wiggler to maintain symmetry, systematic correction was possible while minimizing new errors.

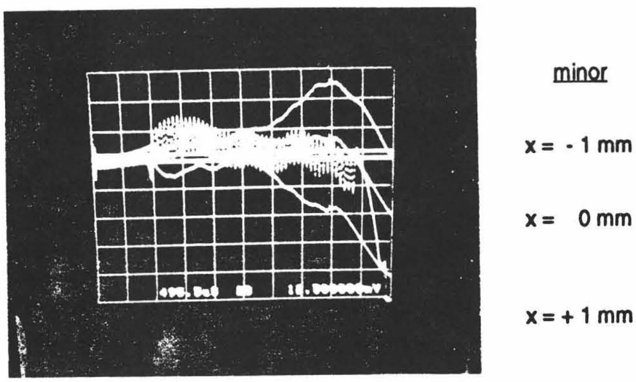


Fig. 4 Minor signal (Bx) has odd symmetry with respect to x at y = 0, indicating a skewed quadrupole error. Major signal is independent of x, as expected.

The final result is shown in Fig. 5, where major and minor signals are shown for all points on the ±1-mm by ± 1-mm grid. Except for the minor signal at x = -1mm, y =- 1 mm, the objective of maintaining the signal average within the wiggles has been achieved. A total of 11 correctors are used to obtain these results. Note that the major signal has an even symmetry with y along the lines x = 0 mm and x = -1 mm. This indicates a sextupole (second order) type error. However, it is not observed at x = +1 mm and thus creates some concern that our model is still not complete.

Conclusions

For the first time, the taut-wire has been used to make a three-dimensional map of magnetic field. Errors are expressed in terms of a two-dimensional Taylor series out to first order. We found that using correctors on only one side of the wiggler introduces new errors, but by using both sides symmetry is maintained and first-order correction becomes possible.

Increase in electron-beam size is minimized by correcting the field for off-axis as well as on-axis particles. In principle, this should yield higher gain and improved performance.

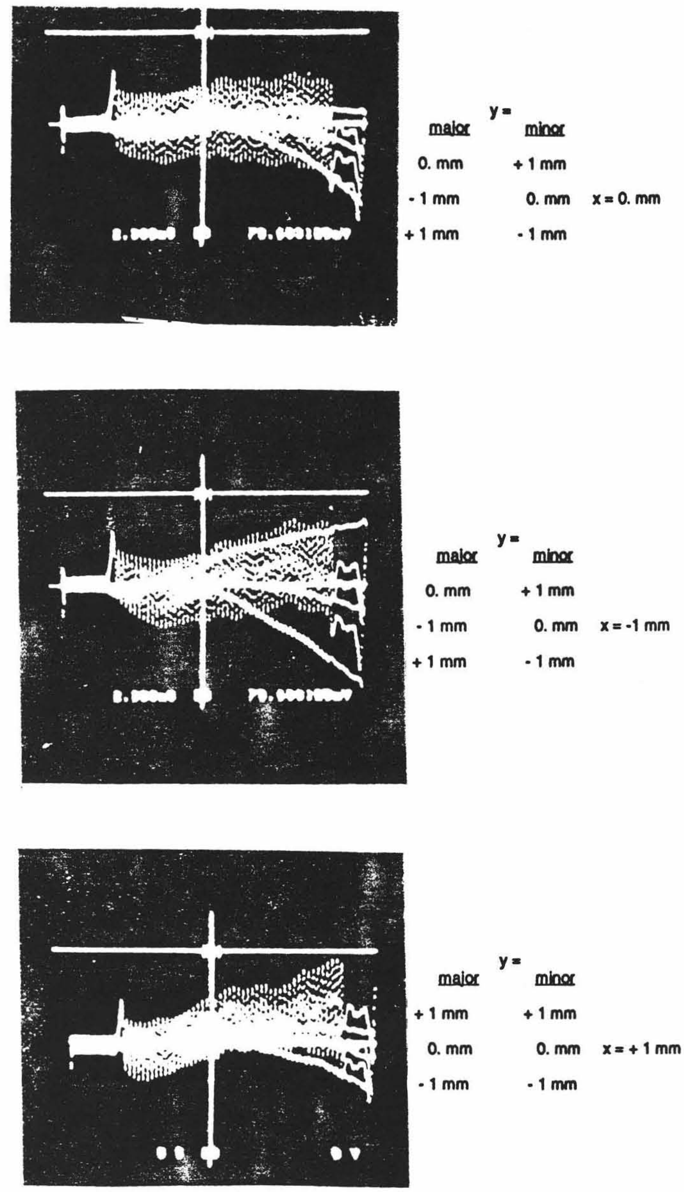


Fig. 5 Final data using eleven correcting elements.

References

[1] R. W. Warren, Nucl. Inst. and Meth. A272 (1988) 257.
[2] D. W. Preston and R.W. Warren, Proceedings of the 13th International Free Electron Laser Conference, Santa Fe (1991) 818.