J. Synchrotron Rad. (1998). **5**, 478–480

Effects of magnets with non-unit magnetic permeability on an elliptically polarizing undulator

Ch. Wang, L. H. Chang,* C. H. Chang, M. C. Lin, C.-S. Hwang and J.-R. Chen

Synchrotron Radiation Research Center, Hsinchu, Taiwan. E-mail: lhchang@alpha1.srrc.gov.tw

(*Received 4 September 1997; accepted 6 November 1997*)

This study employs the three-dimensional magnetostatic code *TOSCA* to assess numerically the effects of NdFeB magnets with non-unit magnetic permeability on an elliptically polarizing undulator. A reduction of a few percent of the on-axis magnetic field strength is predicted. In addition, a deviation of $\pm$100 G cm uncompensated dipole steering is predicted in a phase shift of 180° for the elliptically polarizing undulator EPU5.6 (having a period length of 56 mm) at the minimum gap of 18 mm, which is related primarily to the configuration of the device end scheme. Results presented herein demonstrate that implementing an active compensation mechanism is a prerequisite for minimizing the orbit distortion during phase-shift adjustment, particularly for operating such a polarizing undulator in a third-generation machine having a median energy similar to that of the 1.5 GeV storage ring at SRRC.

Keywords: undulators; magnetic field error; non-unit permeability.

1. Introduction

Undulator radiation has become one of the most brilliant synchrotron light sources since its development in the early 1980's, which accounts for undulators playing an increasingly prominent role in generating synchrotron radiation in storage rings. This development ultimately led to the construction of third-generation radiation facilities such as ALS, APS, BESSY-II, ELETTRA, ESRF and SPring-8, which were designed and constructed primarily for optimizing the use of the undulator's harmonic radiation. Moreover, polarized brilliant light can be emitted from an undulator with modified magnetic configurations (Elleaume, 1989, and references therein), allowing synchrotron-light-source users to identify some difficult or even impossible experiments based on stringent requirements for high-brilliance synchrotron light with various polarization states. Among the undulators, the elliptically polarizing undulator (EPU) proposed by Sasaki *et al.* (1993, 1994) is highly promising. Owing to the EPU's polarization superiority, many construction projects are currently underway, including some at the new-generation light-source facilities such as ALS (Marks *et al.*, 1997), BESSY-II (Bahrdt *et al.*, 1996), SPring-8 (Kobayashi *et al.*, 1996) and SRRC (Wang *et al.*, 1996).

Intrinsically, magnetic gap movement and array phase adjustment must be combined for an elliptically polarizing undulator to select the undulator light with various polarization states and proper harmonic energies. Such a requirement implies that operating an elliptically polarizing undulator is a more complicated task than that of operating a conventional undulator. Consider a situation in which the residual dipole steering deviates during magnetic gap movement and/or phase-shift adjustment. Under such circumstances, an orbit distortion may be unavoidable, thereby hindering the operation of such a polarizing device in the mode of dynamic or continuous scanning. Therefore, the device's residual dipole steering must be minimized so that it is either insensitive or passive (quasi-compensated) with respect to the continuous tuning of the magnetic field strength and phase. Herein, we evaluate the contribution of residual dipole steering due to magnets with non-unit magnetic permeability for an elliptically polarizing undulator. An illustrative example is also provided, involving the polarizing undulator EPU5.6 (having a period length of 56 mm) to be installed at SRRC.

2. Non-unit magnetic permeability

How magnetic non-linearity influences the pure type undulator has received relatively little attention (Zangrando, 1990; Diviacco & Walker, 1993), mainly because NdFeB permanent magnetic blocks usually have a quasi-straight demagnetization curve with a permeability slightly larger than 1 (parallel permeability of 1.03–1.08 and perpendicular permeability of 1.15–1.18). The effects attributed to magnets with non-unit magnetic permeability are usually accompanied by those attributed to magnetic imperfection of the individual magnetic blocks for a conventional undulator. However, a previous study observed a detectable deviation of the residual dipole steering as a function of the array phase for the Helios device at a given gap (Chavanne *et al.*, 1989). This observation cannot be attributed solely to the magnetic imperfection of the individual magnets but also to the permanent magnets with non-unit magnetic permeability. The above effects may profoundly impact an elliptically polarizing undulator operating in a storage ring with a median energy similar to that of the 1.5 GeV storage ring at SRRC (Elleaume, 1996).

This study simulates the effects of magnets with non-unit magnetic permeability on the elliptically polarizing undulator EPU5.6 in two kinds of magnetic configurations: the periodic magnetic structure (modelled with periodic boundary conditions) and the few-period structure (six-period magnetic structure including end magnets with 1/8 period length). A remanence of

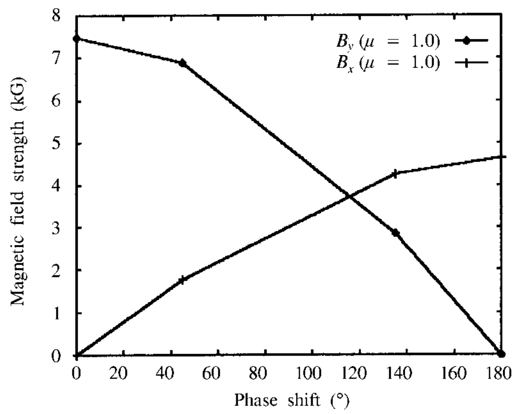

Figure 1
Variation of the on-axis peak magnetic field strength as a function of the phase shift for the elliptically polarizing undulator EPU5.6 at the minimum gap of 18 mm. The permanent magnets are assumed to have unit permeability.

12 000 G is also adopted, allowing us to model the NdFeB permanent magnets. The commercially available code *TOSCA* (Vector Field Ltd, undated) is used for the three-dimensional magnetic field calculation. Simulation results demonstrate that the dipole steering of the periodic magnetic structure is adequately compensated, even for magnets with non-unit magnetic permeability. However, less than 5% reduction in the on-axis peak field strength is predicted. For magnets with unit magnetic permeability, the on-axis peak field strength of the polarizing undulator EPU5.6 at the minimum gap of 18 mm as a function of the phase shift is displayed in Fig. 1. Fig. 2 depicts the corresponding field-strength reduction as a function of phase shift for magnets with parallel and perpendicular permeability equal to 1.05 and 1.16, respectively. Obviously, a reduction in field strength causes a shift in the harmonic energy in comparison with that estimated with unit magnetic permeability. Meanwhile, no phase error is incurred for the periodic magnetic structure. Based on the above results, we can conclude that the effects of the magnets with non-unit magnetic permeability are less relevant for the periodic magnetic structure of an elliptically polarizing undulator.

Our few-period structure contains six magnetic periods to evaluate the effects of the magnets with non-unit magnetic permeability in the end sections of the elliptically polarizing undulator EPU5.6. For the magnets with a non-unit magnetic permeability, simulated results indicate an uncompensated on-axis dipole steering for the symmetric magnetic field component. Meanwhile, such an on-axis dipole steering is well compensated for magnets with unit permeability. Provided that the profile of one of the transverse magnetic field components of the elliptically polarizing undulator is symmetric, the other one is anti-symmetric and *vice versa*. For the anti-symmetric component, its residual dipole steering from each end is automatically compensated for and, therefore, its effect is less relevant. Meanwhile, for the symmetric components, its effect related to the device ends is doubled. For the device EPU5.6, the vertical magnetic field is configured symmetrically. Its residual dipole steering for the NdFeB magnets with non-unit magnetic permeability as a function of the array phase at the minimum gap of 18 mm is shown in Fig. 3. Here, we predict a deviation of the residual dipole steering in $\pm$100 G cm for the polarizing undulator EPU5.6 at 18 mm gap in a phase shift of 180°. Notably, the effects of the magnets with non-unit magnetic permeability result in a non-zero integrated normal sextupole component. Obviously, the effects of the magnets with non-unit magnetic permeability for an elliptically polarizing undulator closely resemble those observed from a hybrid device, which are related primarily to the configuration of the undulator's end scheme.

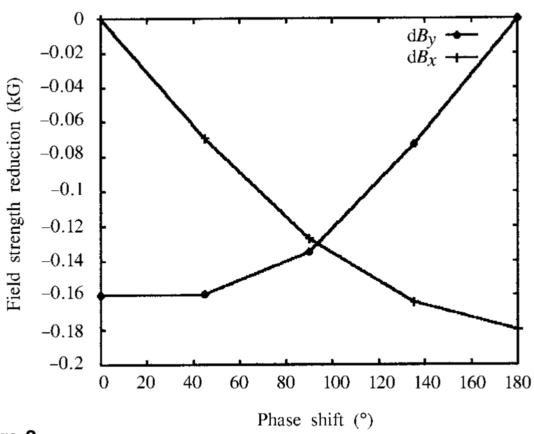

Figure 2
Reduction of the on-axis peak field strength due to magnets with non-unit magnetic permeability ($\mu_{\parallel}$ = 1.05 and $\mu_{\perp}$ = 1.16) as a function of the phase shift for the polarizing undulator EPU5.6 at the minimum gap of 18 mm.

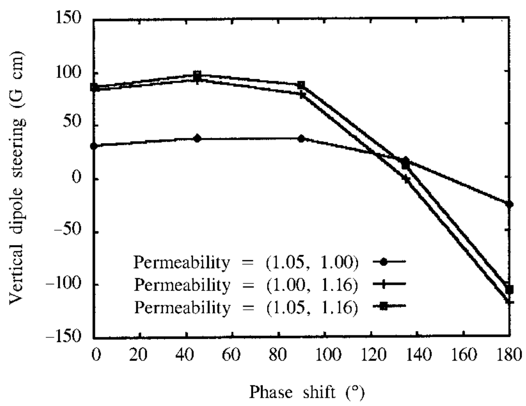

Figure 3
Residual on-axis vertical dipole steering due to magnets with non-unit magnetic permeability as a function of the phase shift for the elliptically polarizing undulator EPU5.6 at the minimum gap of 18 mm.

3. Conclusions

Combining magnetic gap movement and phase-shift adjustment is a prerequisite for an elliptically polarizing undulator to select high-brilliance undulator light with the desired polarization states and harmonic energies. Such a requirement may result in an additional difficulty to operate successfully the polarizing undulator in dynamic mode if the residual dipole steering exists. Our numerical simulation with the three-dimensional code *TOSCA* indicates that the NdFeB magnets with non-unit magnetic permeability significantly contribute to the residual dipole steering. A deviation of the residual dipole steering in $\pm$100 G cm for a shift of the magnet arrays in 180° is predicted for the six-period elliptically polarizing undulator EPU5.6 at the minimum gap of 18 mm. According to our results, such a deviation is related primarily to the magnetic configuration of the device end scheme. Therefore, implementing an active compensation mechanism is a prerequisite for operating the polarizing undulator EPU5.6 at SRRC with free adjustment of the phase shift.

The authors would like to thank the National Science Council of the Republic of China for financially supporting this work in part under Contract No. NSC 86-2613-M-213-003.

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