Conceptual Design for the SRRC Elliptically Polarizing Undulator EPU5.6. Part II: Magnetic Loading and Structure Deformation

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Abstract

An elliptically polarizing undulator consists of four movable magnetic arrays enduring huge quantity of three dimensional magnetic forces which cannot be neglected. Without careful estimation of the magnetic loading on the drive systems or the mechanical parts such as keeper, backing beam, and support frame of an EPU device, the polarized spectral performance may be degraded due to unexpected structure deformation, or even the device might be damaged. In part II of the conference paper, we address our efforts on the determination of the maximal magnetic loading on the individual magnetic arrays, and on the estimation of the resulting structure deformation by using the 3D finite element code ANSYS. The formula for estimation of the spectral intensity degradation due to structure deformation are given.

1 INTRODUCTION

A Sasaki's type elliptically polarizing undulator (EPU)[1] consists of four longitudinally movable pure permanent magnetic arrays, which is one of the most promised schemes for generation of the intensive undulator light with abundant states of polarization. Two 4-meter-long devices of EPU were proposed to form a dual device[2] for installation in the same straight section, in parallel with each other, to generate polarized synchrotron radiation covering a broad range of photon energy from 5 eV to 1400 eV, as the SRRC storage ring operated with 1.5 GeV, which will indeed open the possibility for the SRRC users to perform some experiments which impossible without them, due to their strong requirements on the high degree of circular polarization as well as on the brilliant spectral intensity of the synchrotron light.

Here, we address our efforts on the calculation of the magnetic loading on the individual magnetic arrays of the SRRC device EPU5.6[2] and its resulting structure deformation as a guild-line for mechanical design to avoid any unexpected degradation of the device spectral performance. Similar efforts have been also done in some other laboratories [3][4][5], independently.

2 MAGNETIC LOADING

As well known, the on-axis magnetic field generated by an elliptically polarizing undulator can be expressed[1] as

$$B_x = -\hat{B}_x \sin\left(\frac{\phi}{2}\right) \cos\left(\frac{2\pi}{\lambda_u} z + \frac{\phi}{2}\right) \quad (1)$$

$$B_y = +\hat{B}_y \cos\left(\frac{\phi}{2}\right) \sin\left(\frac{2\pi}{\lambda_u} z + \frac{\phi}{2}\right), \quad (2)$$

where λ_u is the magnetic period length of the device. The phase shift ϕ is defined as

$$\phi = 2\pi \cdot \frac{\Delta z}{\lambda_u}. \quad (3)$$

Here Δz is the relative movement of the upper-front/lower-back arrays to the upper-back/lower-front magnetic arrays of an EPU device. By tuning the phase shift of the device, the amplitudes of the horizontal and vertical peak magnetic field B_x and B_y are varied, and the polarization state of the device emitted synchrotron radiation will be changed. The linear polarized undulator light can be generated by operation of the device with phase shift equal to zero or π or multiple of those; but an elliptically polarized light will be generated if the phase shift is other than those.

Unavoidable, the device's individual movable magnetic arrays endure huge quantity of magnetic loading in three dimensions on themselves which must taken into account during mechanical design for the drive mechanisms as well as mechanical parts such as keeper, backing beam, and support frame to avoid any unexpected degradation of the spectral performance of the emitted radiation due to unacceptable structure deformation, or even damage of the device itself.

On the other hand, the magnetic circuit of a Sasaki's type EPU device is usually assembled by pure permanent magnetic blocks with NdFeB material which is usually dealt, in a good approximation, as current sheet equivalent material for calculation of magnetic field strength at any point outside the magnetic material. Moreover, one of the most convenient way to calculate the magnetic force acting on the individual magnetic arrays of an EPU device is first to evaluate, if available, the magnetic field distribution on a closed surface which enclosed the target, and then to perform a surface integration according to the formula as follows:

$$\vec{F} = \frac{1}{4\pi} \oint_{\Sigma} \left[\vec{B}\left(\vec{B} \cdot \hat{n}\right) - \frac{1}{2} B^2 \hat{n} \right] ds. \quad (4)$$

This formula was employed into the code USEM[6] for calculation of the magnetic loading on the EPU individual magnetic arrays immediately after evaluation of the magnetic field distribution on a given surface. A comparison with the results calculated by the commercial available 3D code TOSCA[8] shows a good agreement. TOSCA code provides a good tool for analysis of force distribution while USEM calculates the magnetic force more efficient and more precise. It's possible to calculate the magnetic loading of the whole device by USEM, but might be very computer time consuming by using TOSCA.

As shown in Fig. 1, the integrated magnetic loading per period on the individual magnetic arrays of the SRRC device EPU5.6 in the vertical (y) and transverse (x) directions during variation of phase shift is always in phase with extreme values at phase shift equal to zero and 180^o, but out of phase with the longitudinal magnetic force which has a maximal value at phase shift equal to $\pm 90^o$. The relevant parameters for the device EPU5.6 can be found elsewhere[2]. It concluded that the EPU magnetic arrays will endure large quantity of longitudinal magnetic loading while generating of the circular polarized light, and of transverse as well as of vertical force during emission of linear polarization light. It is worth to point out that the longitudinal and transverse forces belong to internal force from the point of the mechanical unit including backing beam and keeper, i.e. the transverse and longitudinal loadings on the front and back magnetic arrays have an opposite direction. A distribution map of the longitudinal force density in unit of kgw/cm^2 in the middle plane of the device EPU5.6 with gap equal to 18 mm and phase shift equal to 90^o is shown in Fig. 2. At phase shift equal to 90^o, the transverse loading on the individual magnetic blocks is equal to zero, as shown in Fig. 1, but it does not mean that to be force free in the transverse direction acting on the individual magnetic blocks within one period, but merely indicates that the integrated transverse loading over one magnetic period with such phase shift is equal to zero, as shown in Fig. 3.

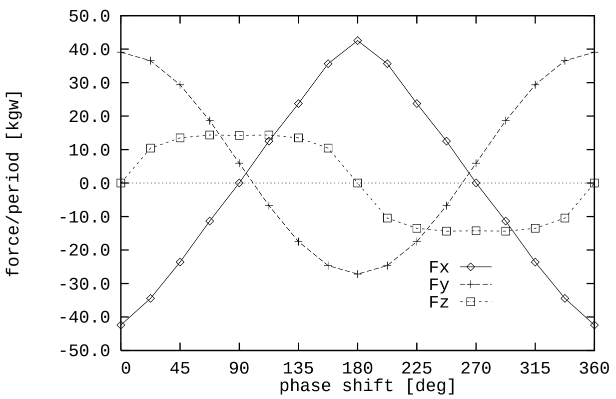

Figure 1: Magnetic loading of SRRC device EPU5.6 on its upper-front magnetic array as a function of phase shift at 18 mm gap.

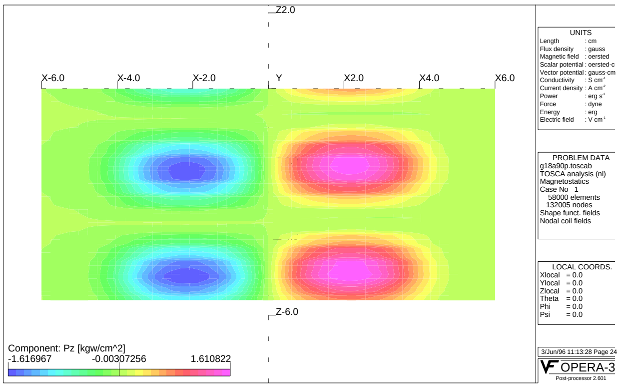

Figure 2: Map for the longitudinal pressure [kgw/cm^2] in the middle plane (in the x-z plane with y=0) of the SRRC device EPU5.6 at 18 mm gap with phase shift equal to 90^o.

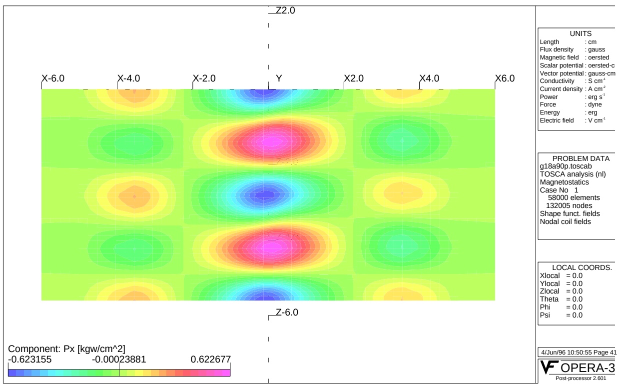

Figure 3: Map for the transverse pressure [kgw/cm^2] in the middle plane of the SRRC device EPU5.6 at 18 mm gap with phase shift equal to 90^o.

3 STRUCTURE DEFORMATION

The structure deformation of the backing beam and the support frame results in a gap-dependent shift of middle plane as well as bending of the magnetic structure. The last one has more serious effects on degradation of the spectral performance and must be controlled within reasonable budget. A rule of thumb for determination of the allowed systematic structure deformation is to divide the error budget into half for structure deformation and half for assembly tolerance and material imperfection. The error budget of structure deformation for a conventional undulator can be estimated by using plane wave approximation which might be also useful for the device of EPU, i.e. the degradation of spectral intensity I may be given as follows:

$$\frac{I_{io} - I_i}{I_{io}} = 1 - \frac{1}{4N^2} \left| \sum_{m=1}^{2N} exp(-i\Psi_m) \right|^2 \qquad (5)$$

Here N is the undulator period number, and Ψ_m the systematic phase error due to structure deformation at pole #m. A more detail discussion will be found elsewhere.

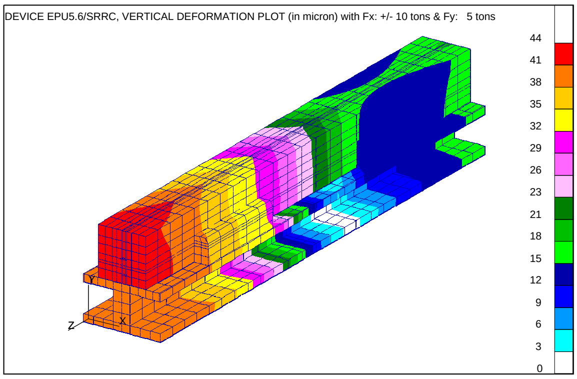

Figure 4: Evaluation of the backing beam deformation in the vertical (y) direction which being applied with 10 metric tons internal transverse force and 5 metric tons external vertical force. The resulting maximal deformation is 44 micron.

The structure deformation of the backing beam and the support frame was then calculated by using the commercial available 3D code ANSYS[9] with help of the commercial code P3/PATRAN[10] for easy modelling of the complicated geometry structure. The shell elements were adopted for plate-like structure in the support frame to reduce the degree of freedom, while the solid elements were used for others, i.e. for the backing beam and support frame including guiding rails and support feet. The second order elements were used for our finite element modelling. For study of the worst case for the backing beam, 10 metric tons internal transverse force and 5 metric tons external vertical force

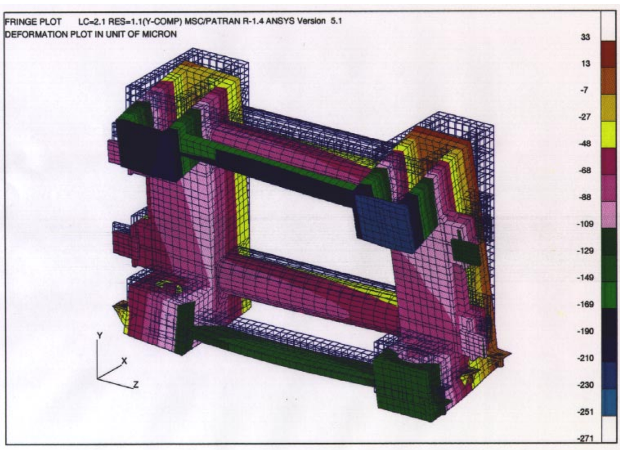

Figure 5: ANSYS results for the structure deformation in the vertical (y) direction. The maximal deformation is about 270μm if 5 metric tons of magnetic loading is applied. The backing beam weight is 2 metric tons for each beam, was considered.

were applied for estimation of the backing beam deformation. The calculation indicates a maximal deformation of 44 μm in the vertical direction, as shown in Fig. 4. The backing beam is made of nonmagnetic material stainless steel 316L. The deformations in the other two directions are small than 10 μm and can be neglected. As expected, the internal transverse force has negligible effects on the structure deformation of the backing beam. The effect of longitudinal loading was not considered here, due to the difficulty of surface force modelling. For the support frame to include the self-weight effect, 7 and 3 metric tons of vertical loading down-word and up-word on the upper and lower part of the support frame were applied for the deformation calculation. A maximal structure deformation of 270 μm in the vertical direction with maximal mechanical stress of 115 Nt/mm^2 is shown in Fig. 5. Further optimization for the cross-section profile of the backing beam and enhancement of the support frame rigidity to reduce the structure deformation are in progress.

4 CONCLUSION

In part II of this conference paper, we emphasize our conceptual design for the SRRC elliptical polarizing undulator EPU5.6 on the calculation of the magnetic loading and its resulting structure deformation.

5 REFERENCES

[1] S. Sasaki, "Analyses for a planar variably-polarizing undulator", Nucl. Instrum. & Mech. A 347, p83-86, 1994.

[2] Ch. Wang et al., "Conceptual Design for the SRRC Elliptically Polarizing Undulator EPU5.6. Part I: Magnetic Configuration and Merit Function Optimization", this conference.

[3] J. Bahrdt, M. Scheer, "An Elliptically Polarizing Undulator for BESSY II: UE-56", 1995/1996.

[4] J. Chavanne et al., "Field Measurement of a Helical Undulator",ESRF-SR/ID-89-29.

[5] S. Marks et al., "ALS EPU5.0: Magnetic Structure Conceptual Design Review", 1995.

[6] The program USEM is a general purpose code developed by Ch. Wang for characterization of the spectral polarized performance emitted from an undulator-like magnetic structure, including considerations on the effects of magnetic field errors, emittance of electron beam, finite size of pinhole, magnetic loading, etc.

[7] J.D. Jackson, Classical Electrodynamics, page 239 of Sect. 6.8, Wiley, New York, 1975.

[8] Program TOSCA, a product of Vector Fields Limited, is a commercial available 3D magnetostatic code.

[9] Program ANSYS, a product of Swanson Analysis System, Inc., is a commercial available 3D code by using finite element method for analysis of the structure deformation, etc.

[10] Program P3/PATRAN, a product of Macneal-Schwendler Corportion (MSC), is a commercial available 3D code for establishment of finite element model which can be used as pre-processor and post-processor for some other structure analysis codes such as ANSYS.