Conceptual design of Superconducting Transverse Gradient Undulator for PAL-XFEL Beamline

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Abstract

Recently, the transverse gradient undulator (TGU) applications are suggested from laser plasma wake-field accelerator (LPWA) to ultimate storage ring (USR). Especially for X-ray FELs, TGU can be used to generate a large bandwidth radiation up to 10%. In this proceeding, a review of PAL-XFEL beam parameters and TGU requirements was done to apply a variable large bandwidth operation to the PAL-XFEL beamlines. Also, the conceptual design of TGU, based on superconducting undulator (SCU) was proposed, and B-field calculation results were introduced for large bandwidth operation modes of PAL-XFEL.

Transverse Gradient Undulator (TGU)

The original TGU concept was introduced to overcome the large electron beam energy spread of an earlier stage of FEL development in the 1980s. The main parameter of TGU α is, the amount of K-value gradient in the transverse direction, defined as

$$\alpha = \frac{\Delta K/K_0}{\Delta x} = \alpha_K/K_0$$

TGU applications are suggested for X-ray FEL by using a small energy spread electron beam by SwissFEL. This application uses a TGU and an RF deflecting cavity to generate the large bandwidth X-ray radiation. A deflected electron beam sees different K-values of TGU and the bandwidth of X-ray FEL can be adjusted by changing the gradient amount of TGU, up to 10% order. By using this scheme, FEL beamlines can provide a variable X-ray FEL bandwidth to meet the requirements of users.

Large Bandwidth Mode for PAL-XFEL

PAL-XFEL, an X-ray FEL user facility, has hard and soft x-ray beamlines based on Self Amplified Spontaneous Emission (SASE). The hard X-ray beamline uses a 10 GeV, 200 pC and 3.0 kA electron beam to provide 0.1 nm hard X-ray FEL by using twenty undulator units. For the soft X-ray beamline, seven undulator units are used to provide 1 nm soft X-ray FEL by using a 3.0 GeV, and 2.5 kA electron beam. Hard X-ray Undulator (HXU) and Soft X-ray Undulator (SXU) of PAL-XFEL are hybrid type undulators and Table 1 shows an undulator system parameters of each undulator systems.

Table 1: Undulator System Parameters of PAL-XFEL Beamlines

Parameters	HXU	SXU
Period, λ_U	26.0 mm	35.0 mm
K	1.973	3.321
B_{eff}	0.812 T	1.016 T
gap_{min}	8.3 mm	9.0 mm
Length	5.0 m	5.0 m

The large bandwidth operation mode of PAL-XFEL requirements was calculated based on the suggested concept of SwissFEL by using the PAL-XFEL beam and undulator parameters. The assumptions were used in this study that a deflecting cavity is installed in front of the undulator beamlines and the TGU beamline, which can provide up to 10% bandwidth X-ray radiation, is installed. The deflected length of the electron beam was assumed as 1mm for both the hard and soft X-ray beamlines for simple calculation. Table 2 shows a required K-value and gradient parameters to generate a 10% bandwidth radiation wavelength, λ_R, for the PAL-XFEL beamlines.

Table 2: Undulator Parameters Required for 10 % Large Bandwidth Operation of PAL-XFEL Beamlines

Beamline	λ_R	K_0	α_K (m^{-1})	α (m^{-1})
Hard X-ray Beamline	0.1 nm	1.973	99.6	50.5
	0.06 nm	1.239	95.2	76.8
Soft X-ray Beamline	3 nm	3.321	130.8	39.4
	1 nm	1.531	109.9	71.8

Conceptual Design of TGU

- Design Parameters

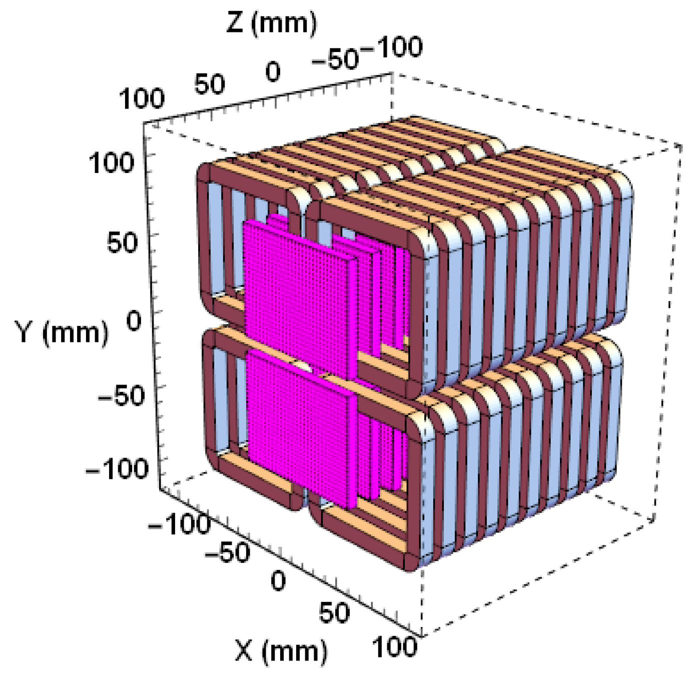

Figure 1: Dual superconducting TGU model for PAL-XFEL soft x-ray beamline.

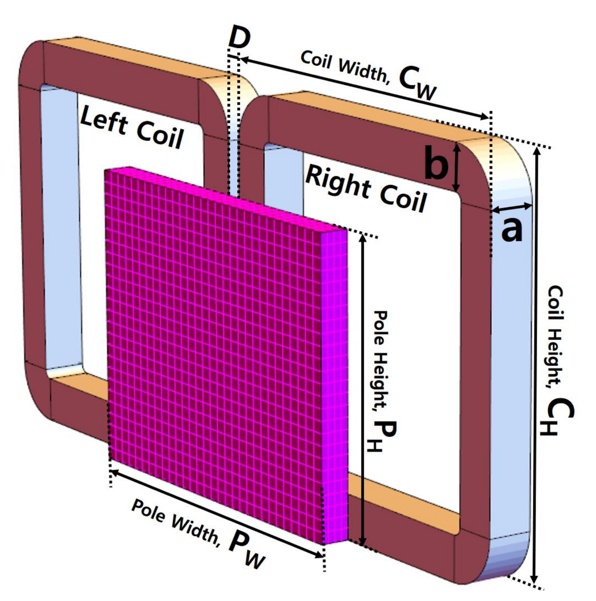

Figure 2: Parameters of superconducting undulator model design.

Table 3: Design and Simulation Parameter Values of Dual Superconducting Undulator for PAL-XFEL

Parameters	Hard X-ray Case	Soft X-ray Case
Period	26 mm	35 mm
a	7.5 mm	10.5 mm
b	7.5 mm	10.5 mm
C_W	30 mm	95 mm
C_H	31 mm	95 mm
D	2 mm	4 mm
P_H	58 mm	90 mm
P_W	16 mm	70 mm
J, Current Density	1200 A/mm²	900 A/mm²
Magnetic Gap	9.5 mm	10 mm

- Magnetic Field Distribution of Superconducting TGU

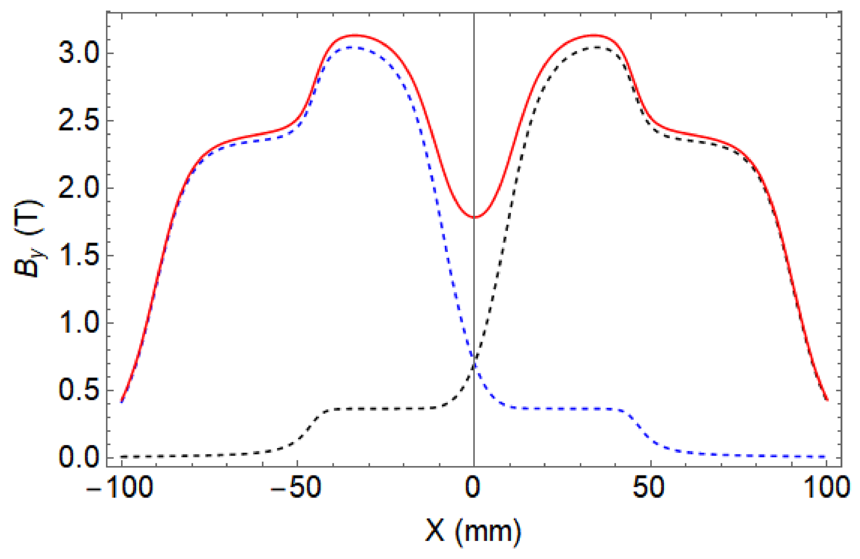

Figure 3: B-field distribution of dual superconducting TGU with J_L = 900 A/mm² and J_R = 900 A/mm² for PAL-XFEL soft x-ray beamline. The blue dotted line shows the By field when J_L = 900 A/mm² and J_R = 0 A/mm². The black dotted line shows B-field distribution when J_L = 0 A/mm² and J_R = 900 A/mm². The solid red line shows one when J_L = J_R = 900 A/mm² and the center position of vacuum chamber has maximum K-value and zero gradients.

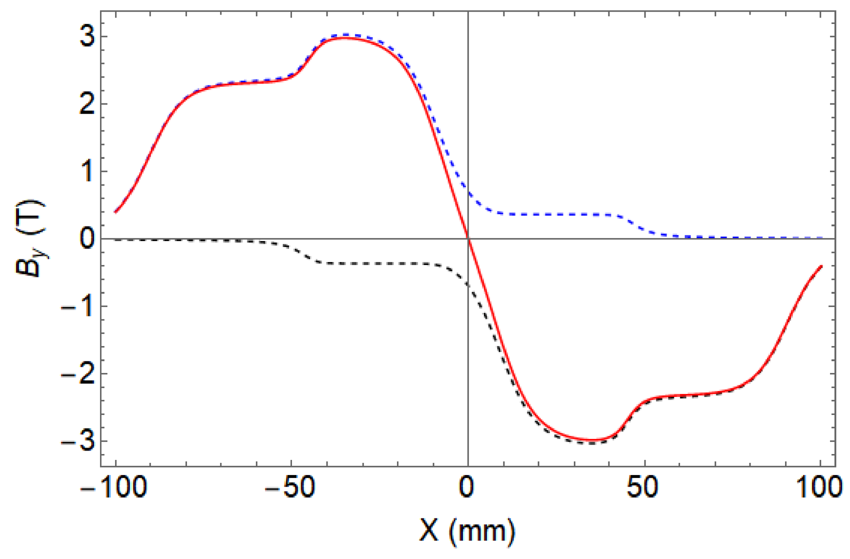

Figure 4: B-field distribution of dual superconducting TGU with J_L = 900 A/mm² and J_R = -900 A/mm² for PAL-XFEL soft x-ray beamline. The gradient is the maximum value, and K-value is 0 for this case.

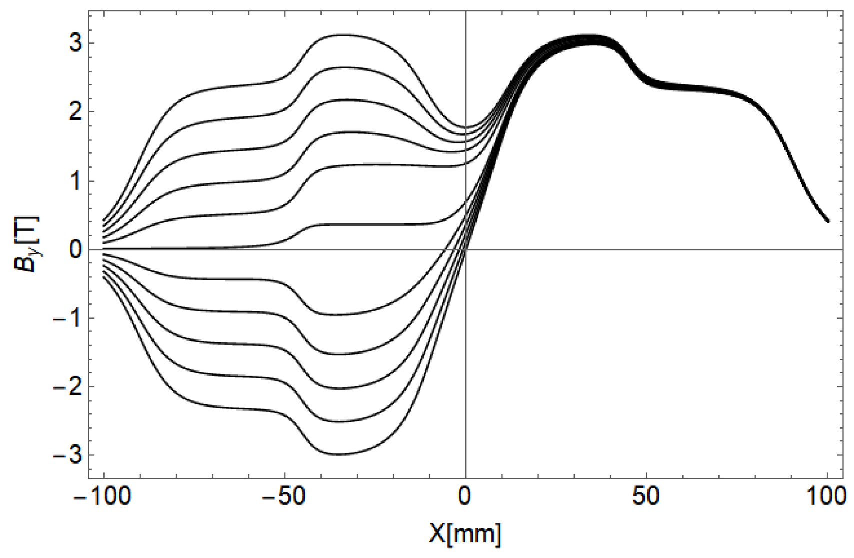

Figure 5: Magnetic field profile for different current ratio between the left and right coils in the model in Fig. 4. The J_R is fixed to 900 A/mm². The left coil current is changed from -900 A/mm² to 900 A/mm² with a 180 A/mm2 step.

Transverse Gradient and K-value

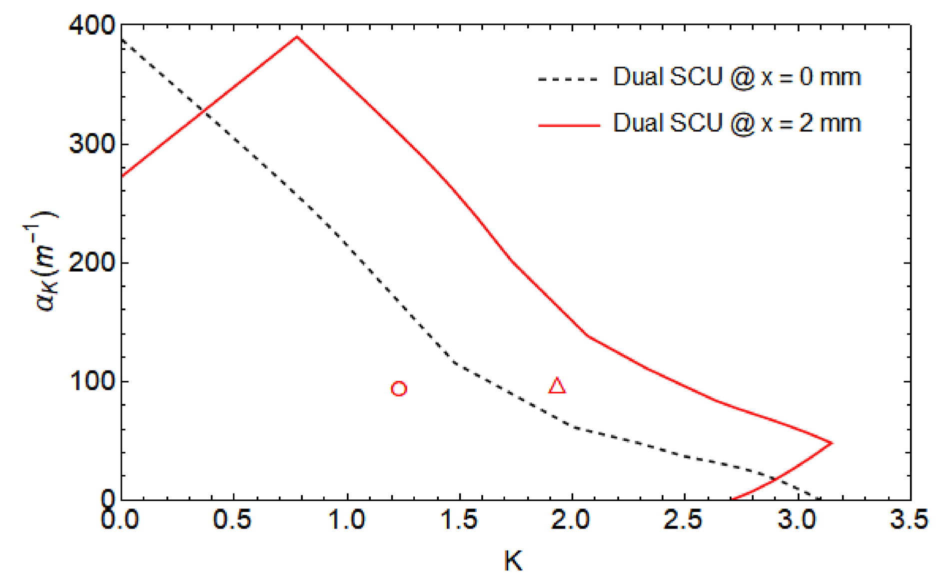

Figure 6: Gradient and K-value for PAL-XFEL hard x-ray beamline TGU and operation points for 10% bandwidth (red dots) when the maximum coil current density is 1200 A/mm².

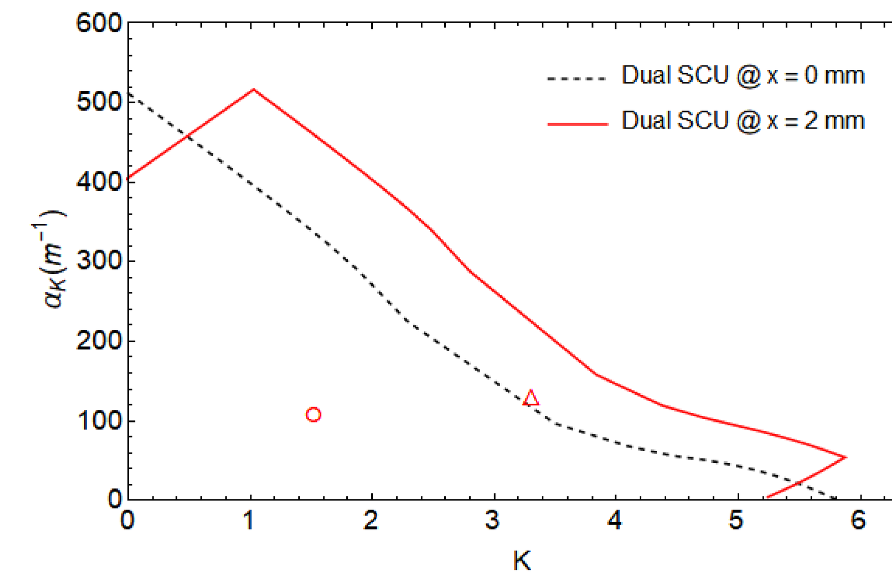

Figure 7: Gradient and K-value for PAL-XFEL soft x-ray beamline TGU when the maximum coil current density is 900 A/mm².

Conclusion

In this study, Large bandwidth operation conditions of PAL-XFEL were calculated, and the conceptual design of a superconducting based TGU was carried out. The conceptual design consists of two normal planar SCUs. This superconducting TGU can change the K-value or gradient by changing the current density ratio between the two coils. By using a x = 2 mm offset point, the superconducting TGU can meet the requirements of the large bandwidth operation of PAL-XFEL. Also, using such an offset point, a reduction in the maximum current density, can be helpful for an SCU operation. Thus, this TGU type based on SCU can be an undulator option for an operation mode with a large bandwidth up to 10% at PAL-XFEL.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (2017R1C1B1012852).