Upgrade of NSRL Optical Klystron for FEL*

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Abstract

A symmetry Optical Klystron (OK) will be upgraded to asymmetry structure for generating more powerful coherent harmonic FEL after measuring buncher parameter from the OK spontaneous emission spectrum. The period of independently adjusted modulator will be extended from 7.2cm to 9.2cm for higher operation energy that will facilitate the progress of Coherent harmonic generation (CHG) FEL experiments. The upgraded OK parameters are listed and checked by the 3-dimensional electromagnetic computation code. Special considerations are given for possible upgrade schemes.

1 INTRODUCTION

One way of Free Electron Laser (FEL) is coherent harmonic generation by firing the electron beam passing through an optical klystron with an external laser, which induces the energy modulation in the modulator by interaction with the optical field. It is transformed into density modulation (bunching) after passing the buncher, and then, the fundamental and odd harmonic coherent radiation is produced in the radiation undulator [1,2].

For this purpose, one symmetry optical klystron (OK) with identical two undulators on its two sides will be upgraded to asymmetry structure for generating more powerful coherent harmonic after measuring buncher parameter from the OK spontaneous emission spectrum [3,4,5]. The present12x7.2cm period modulator will be upgraded to 10x9.2cm by extending 5.6cm magnet system on its ends. In this case, higher operation energy will facilitate the match between the OK and storage ring, which makes experiments easily implemented. The upgraded OK can be operated above the injection energy i.e. 200MeV for coherent harmonic experiments. The Hefei Light Source (HLS) is routinely ramping from the injection energy of 200MeV to the operation energy of 800MeV.

The analysis equations for upgrading the OK are given. The interested induction field is checked by the finite element computation, the 3-dimensional electromagnetic computation software, Opera-3d. The measured B-H curve of the magnet is used in the computation. The typical parameters of the upgraded optical klystron are given. The magnet gaps of the three OK undulator sections can be independently tuned from 40mm to 140mm. The experimental program to measure the coherent harmonic of the OK is given.

2 BASIC THEORY

2.1 Emission wavelength from undulator and resonant energy of electron beam

Emission wavelength from axis of plane undulator is given as [1]:

$$\lambda = \frac{\lambda_0}{2i\gamma^2} \cdot (1 + \frac{k^2}{2} + \gamma^2 \vartheta^2), \ i=1,2,3, \quad (1)$$

Where, ϑ is the angle with respect to the beam axis, i is harmonic number, γ is Lorentz factor, $k=0.934(By/T)\cdot(\lambda o/cm)$ is the undulator deflection factor, By is the peak vertical field, given as [6]:

$$B_y = \frac{2B_r \cdot \sin\frac{\varepsilon \cdot \pi}{M}}{\frac{\pi}{M}} \cdot (1 - e^{-\frac{2\pi h}{\lambda_u}}) \cdot e^{-\frac{\pi g}{\lambda_u}} \quad (2)$$

for

$$\xrightarrow{M=4} B_y = 1.4261 B_r \cdot e^{-\frac{\pi g}{\lambda_u}}$$

pure permanent magnet undulator;

Where, B_r is Magnet remanence, M is the number of magnet blocks per period on one side, λ is period, $h=\lambda/4$ is the height of blocks, g is magnet gap, $\varepsilon=4h/\lambda$ is the fill factor of undulator.

$$B_y = 3.44 e^{-\frac{g}{\lambda_u}(5.08 - 1.54\frac{g}{\lambda_u})} \quad (3)$$

For hybrid undulators [7].

The fundamental resonant energy of electron beam can be given by (1):

$$E/(MeV) = \frac{\gamma}{1.957} = 0.51\sqrt{\frac{\lambda_0}{2\lambda}(1 + \frac{k^2}{2})} \quad (4)$$

It's shown from equation (2) that increasing the period length of modulator and decreasing the wavelength of the fired laser could enhance the resonant energy of electron beam.

2.2 Analysis Computation to Upgrade schemes

Five experimental Schemes of OK are computed using analysis equation 1-4, which are listed in table1. The remanence conditions $B_r = 1.2T$ and $B_r = 1.25T$ offered by magnet supplies are respectively used in pure permanent magnet (PPM) modulators of scheme 1 and 3.

Table1: Five possible upgraded OK parameters in experimental Schemes

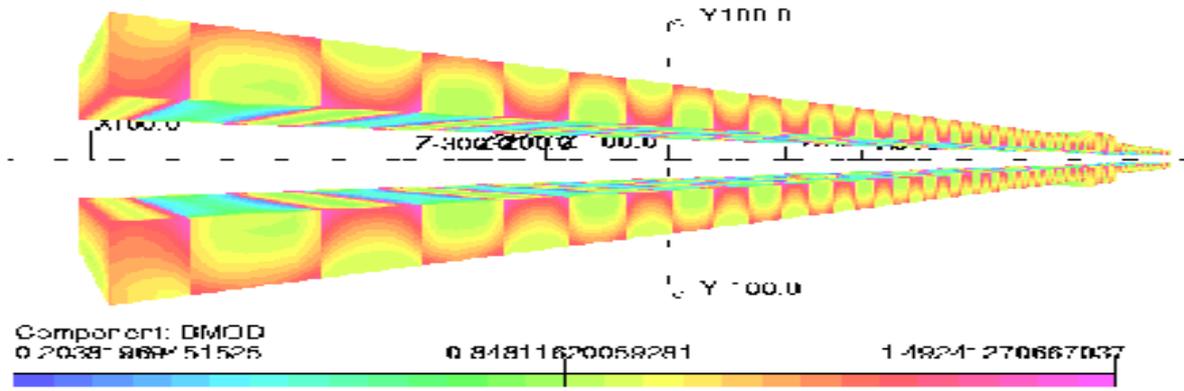| Schemes	Modulator Period/cm @magnet gap	Wavelength of seed laser/nm	Peak field By/T	K	E/(MeV)
1. PPM	7.2@4cm	1060	0.2989	2	163
2. Hybrid	7.2@4cm	532	0.329	2.2	246.33
3. PPM	9.2@4cm	532	0.4368	3.75	425.3
4. Hybrid	9.2@4cm	532	0.5	4.34	484.45
5. Hybrid	10@4cm	532	0.577	5.39	616

Fig. 1: The induction field of Optical klystron

2.3 Upgraded Asymmetry OK

The main parameters of the possible upgrade schemes of optical klystron are listed in table 1. The scheme 3 is selected for having magnet blocks of $23 \times 23 \times 100$ mm^3 in hand although No.5 is the best upgrade scheme for the energy of electron beam in this scheme is 616MeV, where the designed HLS 800MeV storage ring is very stable to be operated with the OK without matching exploration between them.
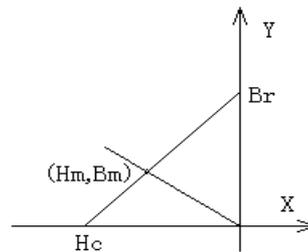
2.4 3d Finite Element (FE) Computation to the Upgraded Asymmetry OK

Fig.1 illustrates the induction field of the 3d electromagnetic computation model of the upgraded OK designed by scheme 3. As shown in fig.2, the measured B-H curve of the magnet is used in the computation. The computed vertical field in the beam axis is shown in fig. 3. Typical OK parameters are listed in table 2.

Figure 2. The $B_r - H_c$ curve of PM Material

Table 2: The OK typical magnetic parameters computed by 3d finite element method and analytic equations

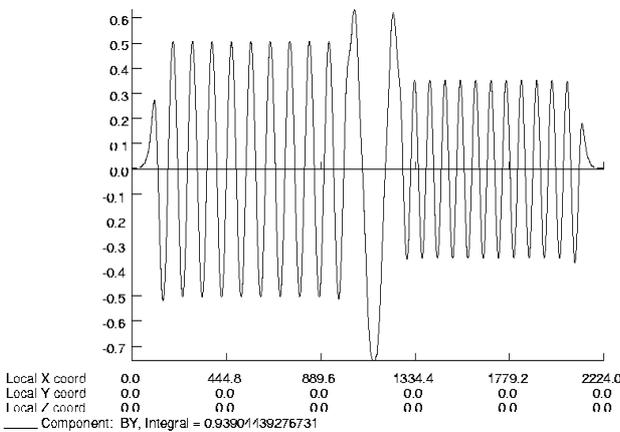|	Modulator	Buncher	Radiator
Gaps/mm	36	36	36
Periods/cm	9.2	21.6	7.2
Computed by OPERA3d By /T	0.506	0.758	0.3523
Computed by analysis equation By /T	0.5214	1.01	0.3557
Errors between them	3.04%	33%	1%
period number	10	1	12

Fig. 3: The computed vertical field in the beam axis

3. CONCLUSIONS

3.1 Matching between the OK and the storage ring with electrons beams is the key issue for successful Experiments. Experiments show that HLS storage ring can be normally operated with the present OK above 530MeV without compensation. So, the No.5 is the best upgrade scheme, which use 10 cm period hybrid undulator as modulator of CHG FEL experiments for the energy of electron beam in this scheme is 616MeV, where the upgraded OK can be incorporated with HLS storage ring without matching for CHG FEL experiments.

3.2 The present selected scheme 3 still needs matching exploration between HLS storage ring test and the upgraded OK, which use 9.2cm period PPM undulator as modulator of CHG FEL experiments for the energy of electron beam in this scheme is 425.3MeV. Even with extremum condition by closing the modulator gap to 36mm, the fundamental resonant energy of electron beam energy could reach 484.85MeV, which is also below the stable energy of 530MeV in HLS storage ring with OK.

3.3 As shown in table 2, magnetic computations of 1D analysis equations give larger peak field than that of 3D FE methods, normalized errors is increased when the period of undulator becomes larger at the same width and gaps of upgraded OK undulators. 1D analysis equations miss the factors of width effects, which are increased while extending the period length [6].

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