COHERENT HARMONIC GENERATION EXPERIMENT ON HEFEI SYNCHROTRON RADIATION SOURCE*

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Abstract

An experiment facility for coherent harmonic generation in ultraviolet spectral range has been built on the storage ring at University of Science and Technology of China. In this paper, the facility, the measurement of the spontaneous radiation spectrum of the optical klystron and preparations for coherent harmonic generation experiment are described.

INTRODUCTION

Hefei synchrotron radiation source at University of Science and Technology of China (USTC) consists of an 800MeV storage ring and a 200MeV injector Linac [1]. The optical klystron (OK) for coherent harmonic generation (CHG) experiment is located in the forth of the four dispersion free long straight sections of the storage ring (Fig. 1).

Although both the injector Linac and the storage ring can be used for FEL experiments, due to limited resources we started with CHG experiment on the storage ring, to gain experience for future Linac based FEL studies using high gain harmonic generation (HGHG) scheme [2]. Concerning the energy of the Linac for FEL experiment, it may be extended to 400MeV in the existing tunnel and klystron gallery for half energy injection into the storage ring, and it is also possible to increase its energy up to 800MeV for full energy injection by replacing klystrons with more powerful ones. Of cause, these will also benefit short wavelength FEL studies. In addition, the nuclear physics experiment hall is available for FEL experiments.

At present, our group collaborates with Shanghai Institute of Nuclear Studies and Institute of High Energy Physics on Shanghai Linac based HGHG type deep ultraviolet FEL (SDUV-FEL). The experience gained from the CHG experiment at USTC will also benefit SDUV-FEL project.

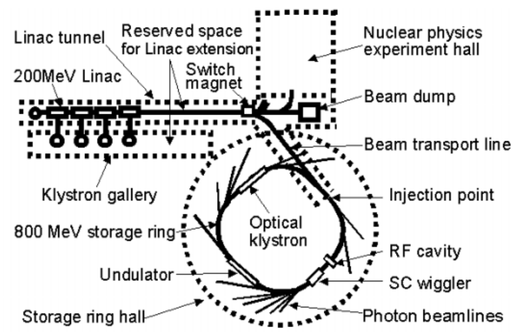

Fig. 1 Layout of Hefei synchrotron radiation source

CHG FACILITY

Figure 2 shows the schematic layout of the CHG experiment facility (bold lines). It consists of an OK, a seed laser and a CHG experiment station, connected by evacuated pipes. The OK is comprised of two undulators separated by a dispersive section. Seed laser light is reflected by mirror 1, focused by two lenses (a telescope) onto the center of the first undulator (modulator), and interacts with the electron beam, causing energy-modulation of electrons. This energy modulation is converted into spatial bunching while traversing through the dispersive section. In the second undulator (radiator) the micro-bunched electron beam emits coherent harmonic radiation. To protect the CHG experiment station from strong bremsstrahlung, coming out of the long straight section where the OK is located, Mirror 2 and mirror 3 are placed on the path of the output radiation beam, forming a parallel displacement. Radiation shielding is mounted on a support behind

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mirror 2. Both mirror 2 and mirror 3 reflect the desired output harmonic radiation and transmit other harmonics and the seed laser. The connecting pipes are evacuated to prevent air disturbance and absorption, and they are isolated from the ultra-high vacuum environment of the storage ring by upper-stream and down-stream quarts glass windows.

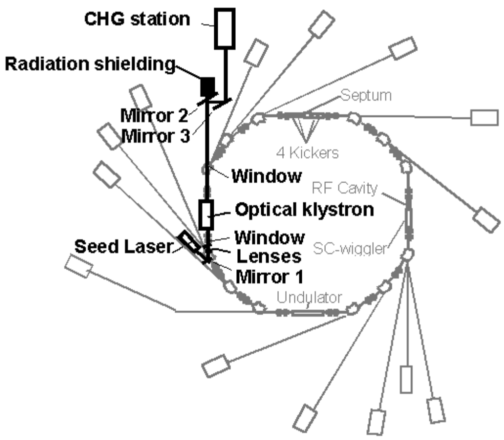

Fig. 2 Layout of CHG Facility

At the beginning, a symmetrical permanent magnet OK was constructed, and a homemade Nd:YAG laser of 1.06μm was chosen as the seed. Output of the third harmonic was desired. The OK is made of NdFeB blocks. The period length and period number of each undulator is 72mm×12. The dispersive section has only one period of 216mm. The magnet gaps of the three sections can be adjusted independently from 40mm to 140mm. The minimum gap is for CHG experiment due to beam lifetime requirement, while the maximum gap is for synchrotron radiation operation of the storage ring. In CHG experiment, the gap of the dispersive section must be adjusted to optimize the output, and the operation energy of the storage ring must be 163MeV, which is lower than the injection energy of the storage ring. Electrons must be decelerated after injection. This was tested successfully, when the gaps of the OK sections were at 140mm. But it was very difficulty to store sufficient beam current at 163 MeV when the gaps of the modulator and the radiator were set at 40mm. This led us to consider upgrade of the CHG facility to run the storage ring above 200 MeV. Meanwhile, we started R&D of SDUV-FEL, which is based on a 300 MeV Linac. Obviously, it is better to take 200~300 MeV as the operation energy of the storage ring for the upgrade program of the CHG experiment facility.

In the upgrade, the wavelength of the seed is changed to 532 nm, and the NdFeB blocks of the modulator are replaced with the ones of the recent built undulator, which has been installed in the third long straight section. The period length of the modulator increases from 72mm to 92 mm, resulting in an unsymmetrical OK. The modulator resonates at the wavelength of the seed, but the radiator resonates at its harmonics. The varying range of electron energy and the corresponding varying range of modulator strength and radiator strength are listed in table 1.

Table 1 Electron energy and undulator strength

Output harmonics	3	2
Electron energy (MeV)	240~400	200~325
Modulator strength K_m	1.77~3.5	1.25~2.7
Radiator strength K_r	0.4~2.0	0.5~2.0

Table 2 Sample parameters

Electron beam (Single bunch mode)	Energy (MeV)	251
	Energy spread	0.016%
	Beam current (mA)	10
	Beam size (mm,mrad) σ_x, σ_y, σ_z, σ_x', σ_y'	0.518,0.051,11.3, 0.024,0.015
Seed laser	Wavelength (nm)	532
	Power (MW)	30
	Radius (mm)	0.5
Optical klystron	K_m	1.9
	K_r	1.26
	Dispersive section parameter N_d	90
Output radiation	Wavelength (nm)	266
	Power (KW)	54
	Spectral ratio	1.9×10^9

As a sample, a set of parameters of the facility after upgrade, the calculated output power and spectral ratio are listed in table 2 [3]. The spectral ratio for a harmonic is defined as the ratio between coherent intensity and incoherent intensity in an infinitesimal solid angle aperture on the axis and infinitesimal bandwidth at that harmonic [4].

SPONTANEOUS RADIATION

Because the spectral ratio is proportional to the square of modulation rate of spontaneous radiation spectrum of an OK, deep modulation is desired [5]. The spontaneous radiation of the symmetrical OK was measured. At the beginning, the measured modulation rate was only 0.23. After re-alignment and adding an aperture of small diameter the modulation rate reached 0.4. For further improvement, numerical simulation was carried out, and results show that when the vertical orbit offset of the electron beam in the storage ring is 2mm and 1mm the modulation rate is 0.43 and 0.74 respectively. When orbit correction was carried out, the measured modulation rate reached 0.75 (Fig. 3).

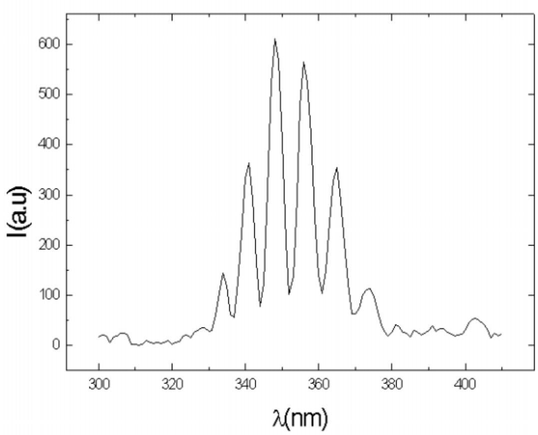

Fig. 3 Modulated spontaneous radiation spectrum of the optical klystron

CHG MEASUREMENT SYSTEM

The main interest is to measure the spectral ratio. Figure 4 shows the layout of the measurement system. The difficult is the repetition rate of the spontaneous radiation pulses is much higher than that of the seed. In single bunch operation mode of the storage ring the former is 4.343 MHz. Due to the damping time of the electron beam in the storage ring and the performance of the seed laser, the latter is 1~10 Hz. To select and measure any coherent radiation pulse or incoherent radiation pulse from the radiation pulse train, a high on-off ratio ICCD is used as an optical shutter. The synchronization system is also shown in Fig. 4. An aperture of small diameter is placed before the spectrometer to eliminate off-axis radiation. The measured ratio is integral ratio. The spectral ratio can be calculated, according to the actual solid angle aperture and bandwidth of the measurement system.

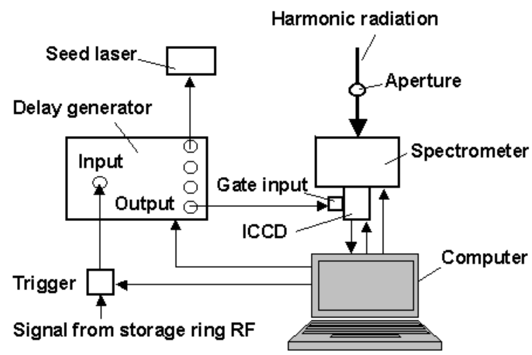

Fig.4 Measuring and synchronizing system

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