Relative Timing Jitter Effects on Two-stage Seeded FEL at SHINE

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ABSTRACT

The synchronization between the ultrashort electron beam and external seed laser is essential for seeded FELs, especially for a multi-stage one. In this paper, we demonstrate a simple method to obtain the correlations between the pulse energy and relative timing jitter for evaluating the corresponding effects. In this method, the sensitivity of the output FEL performance against electron beam properties is demonstrated by scanning the electron beam and seed lasers, and the fitted curve is used to predict the pulse energy in different timing jitter by random sampling. The results indicate that the pulse energy of the first-stage EEHG is more stable than the second-stage HGHG. Meanwhile, the rise of bunch charge from 100 pC to 300 pC can reduce the timing control requirement by a factor of least 3 for the RMS timing jitter in our numerical simulations based on the parameters of Shanghai High-Repetition-Rate XFEL and Extreme Light Facility. The timing jitter study can demonstrate the feasibility of the EEHG-HGHG cascading scheme in different current profiles for generating Fourier transform-limited soft X-ray FEL.

EEHG-HGHG CASCADING SCHEME

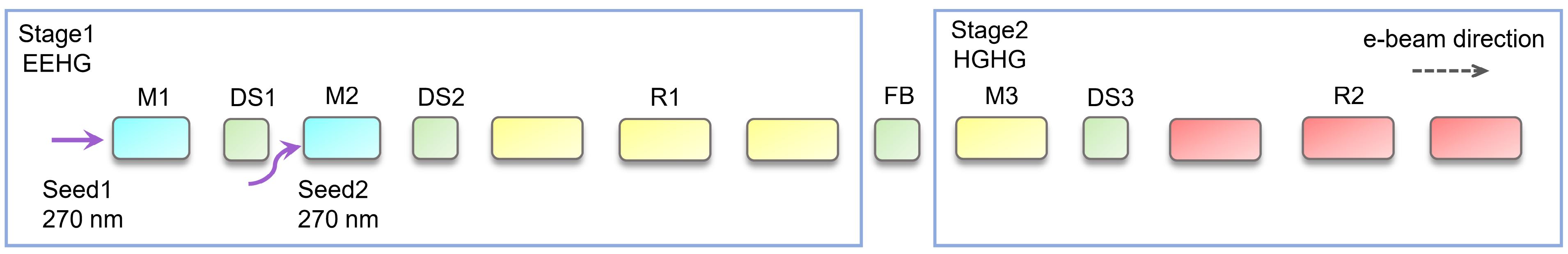

Fig.1 Schematic layout of two-stage EEHG-HGHG configuration for SHINE FEL-II line. Stage1 is composed of two modulators (M1, M2), two dispersion sections (DS1, DS2), and a long radiator (R1). For maintaining the laser-beam interaction in Stage2, the electron beam will be a delay in a magnet chicane (FB) with additional length. Then, Stage1 output will work as a seed laser in the Stage2 HGHG which is composed of one modulator (M3), one dispersion section (DS3), and a long radiator (R2).

Table 1: Main simulation parameters of SHINE FEL-II

Specifications	Electron beam
Energy	8 GeV
Relative energy spread	0.01 %
Normalized emittance	0.2 mm·mrad
Peak current	1500 A (Gaussian)
Bunch charge	100 /300 pC
Bunch length	60 /180 fs (FWHM)
Specifications	**Seed laser**
Peak power of seed1	8.5 GW (Gaussian)
Peak power of seed2	13.5 GW (Gaussian)
Duration	20 fs (FWHM)
Wavelength	270 nm
Rayleigh length	3.52 m

TIMING JITTER STUDY

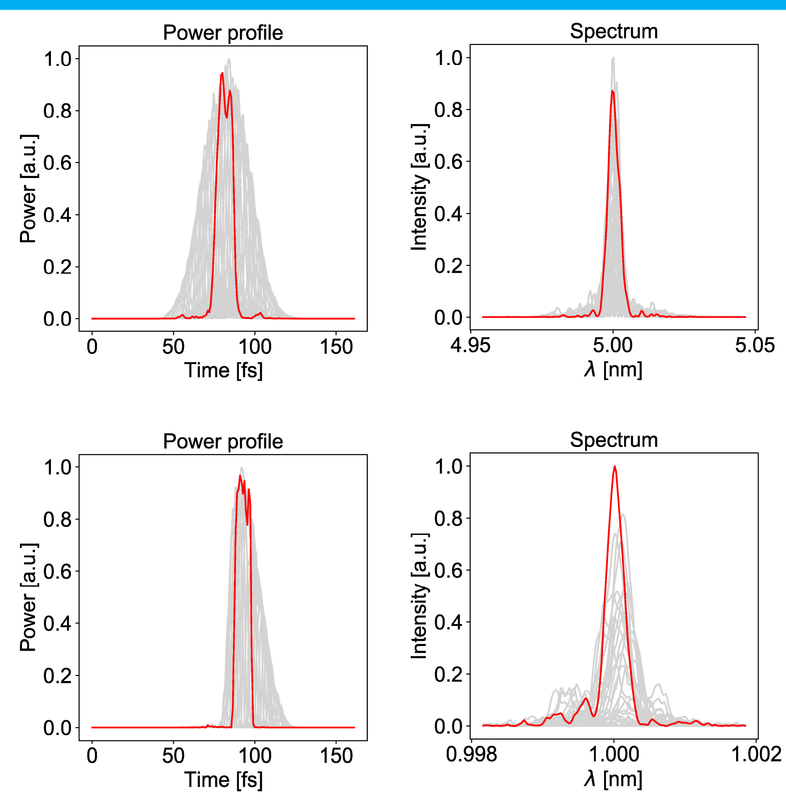

Fig.2 The temporal power profile and spectrum of the first-stage EEHG (upper) and the second-stage HGHG (bottom) FEL performance, respectively, by scanning the relative delay between the electron bunch and seed lasers of 70 fs.

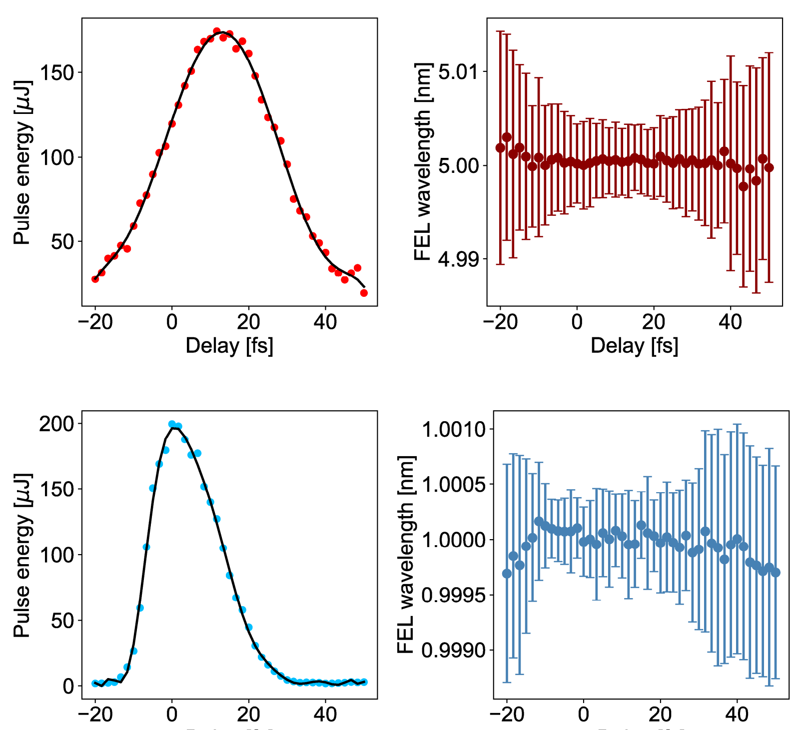

Fig.3 Sensitivity of the FEL performance against electron beam properties of the first-stage EEHG (upper) and the second-stage HGHG (bottom). The delay = 0 corresponds to the maximum final output FEL pulse energy.

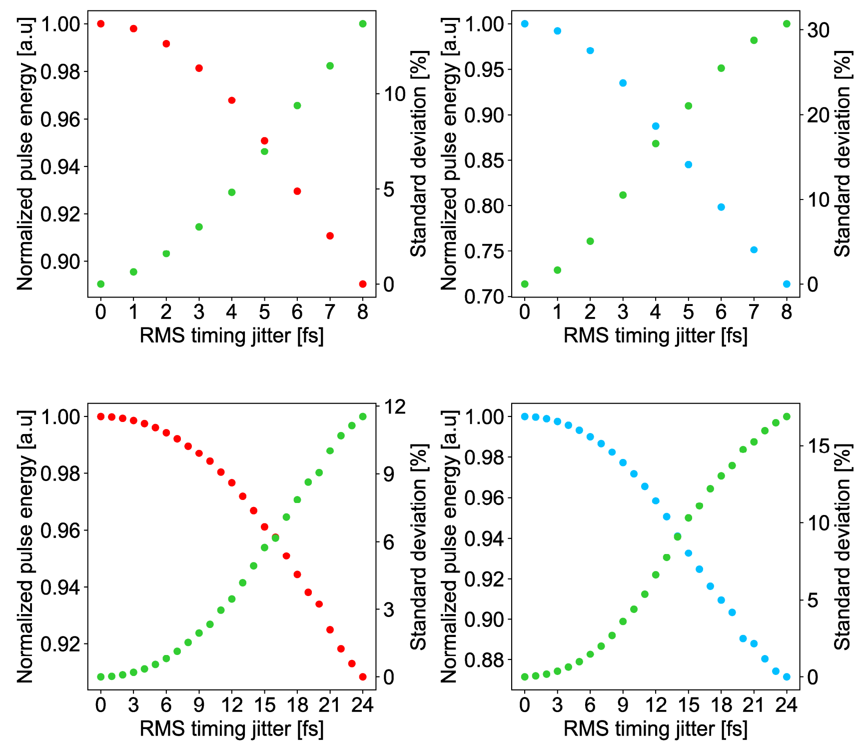

Fig.4 The correlations between the pulse energy normalized by mean pulse energy (without timing jitter) and RMS timing jitter in different cases with bunch charge of 100 pC (upper) and 300 pC (bottom).

CONCLUSION

In this paper, a simple method, which demonstrates the pulse energy is a function of relative delay between the electron beam and seed lasers, has been applied to predict the effects of relative timing jitter. The timing jitter study for SHINE demonstrates the impact of relative timing jitter on two-stage FEL pulses performance and evaluates the tolerance of ultrashort electron beam with Gaussian profile. The bunch length increases by 3 times will reduce the control requirement for RMS timing jitter by least 3 times. The femtosecond seed lasers should precisely manipulate to tailor the ultrashort electron beam; however, it is a challenge to synchronize each other. From another perspective, the seed laser is relatively shorter and cannot avoid the incoherent radiation at high harmonics, when the bunch length increases. It is concluded that one should take the balance of the synchronization problem caused by the timing jitter, and the radiation spectrum degradation caused by short seed lasers into account, optimize the current profile, and finally realize the stable soft X-ray free-electron

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