Towards one machine, two purposes: using a common SC linac for XFEL and ERL simultaneously

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Abstract The linac based XFEL and ERL are advanced (or, say, 4^{th} generation) light sources, with different electron beam parameters and different advantages. However, the linac used for XFEL and ERL should provide very advanced beams with high energy, high peak and/or average current, very low emittance and low energy spread, thus making the linac very complicated and expensive. To share the XFEL and ERL advantages and save the construction-operation budget, a proposal of using a common superconducting electron linac for hard X-ray XFEL and ERL is described in this paper. The interactions between the XFEL and ERL beams via the accelerating structure are studied and the result is positive.

Key words electron linac, XFEL, ERL

PACS 41.60.Cr, 41.60.Ap, 29.20.Ej

1 Introduction

Advanced (or, say, 4^{th} generation) light sources require a high quality electron beam interacting with a high quality insertion device (undulator). The electron beam should have a high peak current or a high average current, a very low emittance and an energy spread to produce a coherent X-ray with high brilliance and a narrow spectrum band (good energy purity) by interacting with an insertion device.

The advanced electron linear accelerator (Linac) can provide such a high quality beam, equipped with a high current and low emittance electron gun, a bunch compression system, a very stable RF power supply with a very precise low level control system (e.g. RF amplitude jitter of 0.1% and phase jitter 0.1°), and a very complex and precise beam monitoring system. All these components make the linac very difficult and expensive.

There are two types of advanced light sources being used or studied. One is the X-ray free electron laser (XFEL) [1] based on an advanced electron linac producing a coherent beam both in longitudinal and transverse phase spaces and with a beam energy higher than 6 GeV; the peak brilliance of XFEL is unprecedented (about 10 orders over 3^{rd} light sources), and the optics pulse length is in the level of 100 fs which makes ultrafast process research possible. Another one is the Energy Recovery Linac (ERL) [2–4] based on an advanced electron linac and one path "circular part" for a partially transverse coherent electron beam. The most important advantages of the ERL are that it can use the power source economically, provide more than 30 photo beam lines simultaneously for users and the optical pulse length of ERL is in the level of ps. XFEL and ERL are complementary to each other and cannot be replaced by each other.

According to the descriptions of the advanced linac based XFEL and ERL mentioned above, we recently proposed an advanced hard X-ray light source using one linac for two purposes, i.e. for both XFEL and ERL simultaneously, as one of the candidates for the Beijing Advanced Light Source. Its layout is shown in Fig. 1.

2 HOM and wakefield

The key issue to reach this goal is mainly that the interactions between the XFEL beam (pulsed with a high bunch charge of about ~ 1 nC) and the ERL beam (cw beam with a low bunch charge of about

Received 13 February 2009

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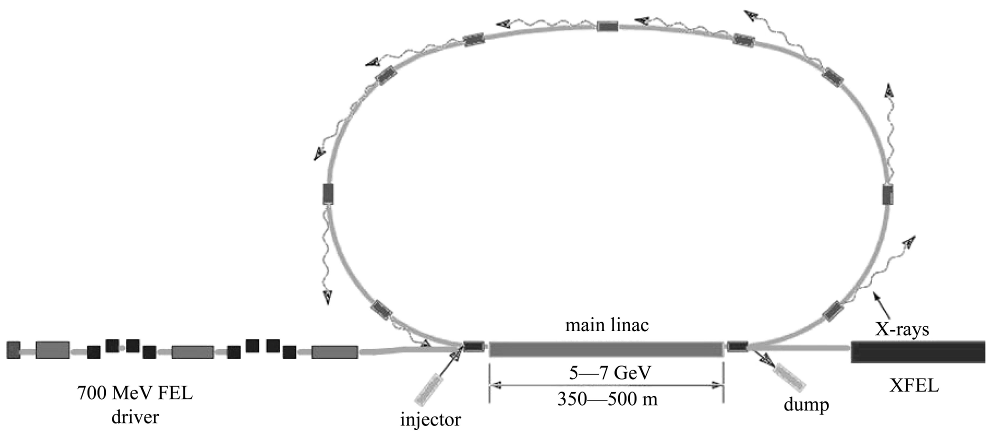

Fig. 1. Schematic layout of the Advanced Light Source ("One machine, Two purposes").

77 pC), via accelerating structures, may produce beam instabilities. We have studied the interactions between the XFEL and ERL beams through a common linac accelerating structure. According to the present study result of Cornell, the number of cavity cells used for ERL is less than 9 with a smaller number of HOMs than TESLA-9 cell cavity. So we use the TESLA-9 cell superconducting structure with known high order modes (HOMs) [5] (shown in Table 1) to study the interactions between the XFEL and ERL beams. We added all the known HOMs acting on the beams as a long range wakefield. The time structures both for the XFEL beam and ERL beam are cited from the TESLA-XFEL design (10–20 GeV) [5] and the Cornell ERL design (5–7 GeV) [4], and are listed in Table 2.

Table 1. HOMs of the TESLA 9-cell cavity.

frequency/ GHz	loss factor/ (V/pC/m^2)	R/Q/ (Ω/cm^2)	$Q(10^4)$
TM_{110}-like			
1.7949	21.70	0.77	1.0
1.8342	13.28	0.46	5.0
1.8509	11.26	0.39	2.5
1.8643	191.56	6.54	5.0
1.8731	255.71	8.69	7.0
1.8795	50.80	1.72	10
TE_{111}-like			
1.6506	19.98	0.76	7.0
1.6991	301.86	11.21	5.0
1.7252	423.41	15.51	2.0
1.7545	59.86	2.16	2.0
1.7831	49.20	1.75	0.75

From Table 2, one can see that there are about 121 ERL bunches between the adjacent two XFEL bunches. The long range transverse wakefield contributed by all TE_{111}-like and TM_{110}-like HOMs can be written as:

$$W(t)=\sum_n \frac{2k_n c}{\omega_n}\exp\left(\frac{-\omega_n t}{2Q_n}\right)\sin(\omega_n t),$$

where ω_n is the $n^{\rm th}$ HOM's frequency, k_n the loss factor ($V/C/m^2$), and Q_n the quality factor. This long range transverse wakefield is shown in Fig. 2.

Table 2. Typical XFEL and ERL beam time structures.

beam types	XFEL	ERL
beam pulse repetition rate	5 Hz	1.3 GHz
bunch train length	1.07 ms	—
bunches/train	11500	—
bunch length	80 fs (rms)	2 ps
bunch spacing	93 ns	0.77 ns
bunch charge	1 nC	77 pC
normalized emittance	1.0×10^{-6} m	1.0×10^{-6} m
accelerating gradient	18 MV/m	18 MV/m

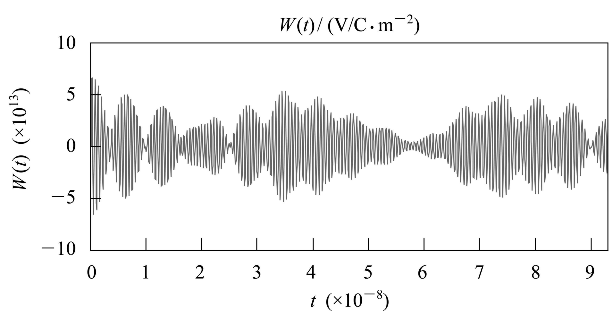

Fig. 2. The long range wakefield contributed by all TE_{111}-like and TM_{110}-like HOMs.

3 Transverse kicks on beams

The transverse kick of the $j^{\rm th}$ bunch after transversing one cavity due to the former bunches is expressed as

$$\theta_j=\sum_{i=1}^{j-1}\frac{y_iq_i}{E_i}\frac{2k_ic}{\omega_n}\mathrm{e}^{-\omega_n\mathrm{i}\Delta t/2Q_n}\sin(\omega_i\mathrm{i}\Delta t),$$

where y_i, q_i, and E_i are the offset with respect to the cavity axis, the charge and the energy of the ith bunch, respectively.

The transverse kicks (θ) acting on the ERL beam and on the FEL beam due to the above wakefield have been calculated and are shown in Fig. 3 and Fig. 4, respectively.

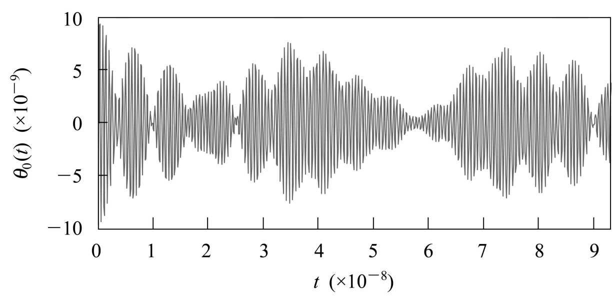

Fig. 3. The transverse kicks (θ) acting on the ERL beam.

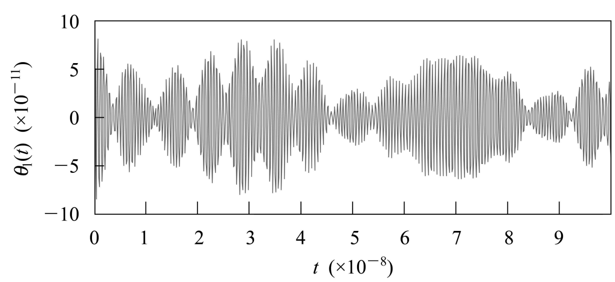

Fig. 4. The transverse kicks (θ) acting on the XFEL beam.

In Fig. 4, the long range transverse wakefield is contributed by the 121 ERL bunches between two adjacent XFEL bunches, t is the time between the XFEL bunch and the last ERL bunch, and $\theta_1(t)$ are the kicks on the XFEL bunch contributed by the 121 ERL bunches. By these figures, one can see that the kicks acting on the ERL and XFEL beams are less than 9×10^{-9} rad and 7×10^{-11} rad, respectively, and are negligible.

4 Merger

A generic one-loop ERL has a gun system, a merger, a linac, a loop and, finally, a dump. A merger, i.e. a system merging different energy beams, is an intrinsic part of any ERL loop located between the gun and the main linac. Due to the different energies, the trajectories of the high energy and low energy are bent on different angles in the same bend, hence leading to the combination of the different energy beams. The merger should merge three kinds of electron beams: the electron beam from the DC photocathode injector, the electron beam from the FEL injector driver and the returning ERL beam in our proposal. In Ref. [6], we have given a physical design of the merger section which merges three kinds of electron beams for our proposal (shown in Fig. 5).

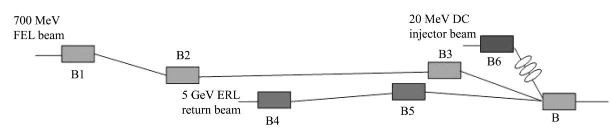

Fig. 5. The schemetic setup of the merger.

5 Conclusion

In conclusion, we have studied the multibunch effect combining the XFEL and ERL. The result shows that a compact combination of XFEL and ERL with a common SC linac is feasible. This compact hard X-ray light source is one of the candidates for the Beijing Advanced Light Source in the near future.

Thanks go to Prof. Alex Chao and Dr. Zhirong Huang from SLAC for useful discussions and suggestions.

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