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Study of Microbunching Instability in SHINE linac

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Introduction

Microbunching instability (μBI) usually exists in the linear accelerator (linac) of a free electron laser (FEL) facility. If it is not controlled effectively, the beam quality will be damaged seriously and the machine will not operate properly. As a typical example, the microbunching instability in the linac of the proposed Shanghai high repetition rate XFEL and extreme light facility (SHINE) is investigated in detail by means of both analytical formulae and simulation tools.

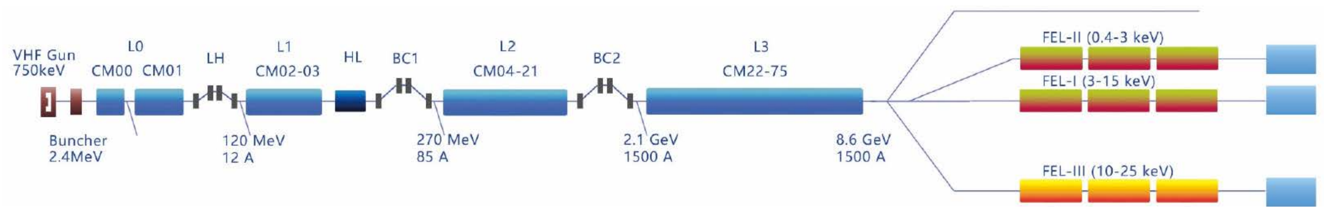

Figure 1. Schematic layout of Shanghai high repetition rate XFEL and extreme light facility (SHINE).

Principles & simulation

As the beam passes through a bunch compressor, for example, a magnetic chicane, the energy modulation introduced by those effects is transformed into density modulation and may thus introduce the so-called microbunching effects. In certain situations, the microbunching effects can be so large that the microbunching instability can also take effects, and the final gain of the instability can become significant. On the other hand, the FEL process has a high demand for electron beam quality in terms of peak current, emittance, energy spread, etc. Therefore to preserve the beam quality, the microbunching effects must be studied in the design stage of the machine.

As usual, the SHINE linac includes multiple stage of bunch compressor. In the physical design, two bunch compressors are employed and the third one is reserved as a spare to compress the bunch current up to 3 kA. The main parameters of the bunch compressors are listed in table 1.

The microbunching is modelled with the simulation code ELEGANT [1], which is commonly considered as a high-fidelity code in accelerator and beam physics. Due to the computing power, 20 million macro-particles are used to simulate 100 pC charge in the simulation. However, referring to [2], this number of macro-particle are nearly enough for this amount of charge.

To study the microbunching effects, equation (1) [3] is used to estimate the wavelength of the microbunching at the peak. Or in other words, the smearing of microbunching from the uncorrelated energy spread across the chicane is not effective until

$$\lambda_0 \leq \left|\frac{2\pi R_{56}}{1+hR_{56}}\right| \sigma_\delta \equiv \lambda_c, \qquad (1)$$

Table 1. Main parameters of bunch compressors in SHINE linac.

	BC1	BC2	BC3 (proposed)
Beam energy (MeV)	269	2156	5762
Compression ratio	7	15	2
R_{56} (mm)	-60.8	-34.6	-7
Total length (m)	12.2	24	23.95

With the magnetic chicane parameters in table 1 and the corresponding beam parameters, we have λ_c = 70.9 μm for BC1, and λ_c = 15.1 μm for BC2 which corresponds to the initial density modulation of λ_c ≈ 106 μm before BC1. Therefore, one may conclude that the peak of the overall microbunching gain shall locate in the vicinity of 72.7 μm and 106 μm in wavelength.

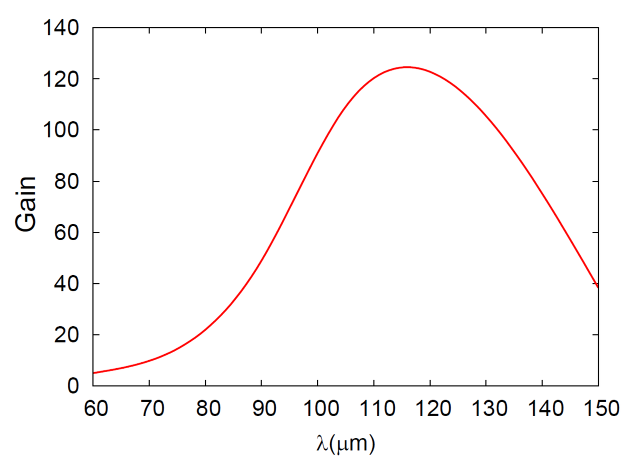

Figure 2. Final gain curve computed from the residual current of the FFT of beam obtained by Elegant [1]

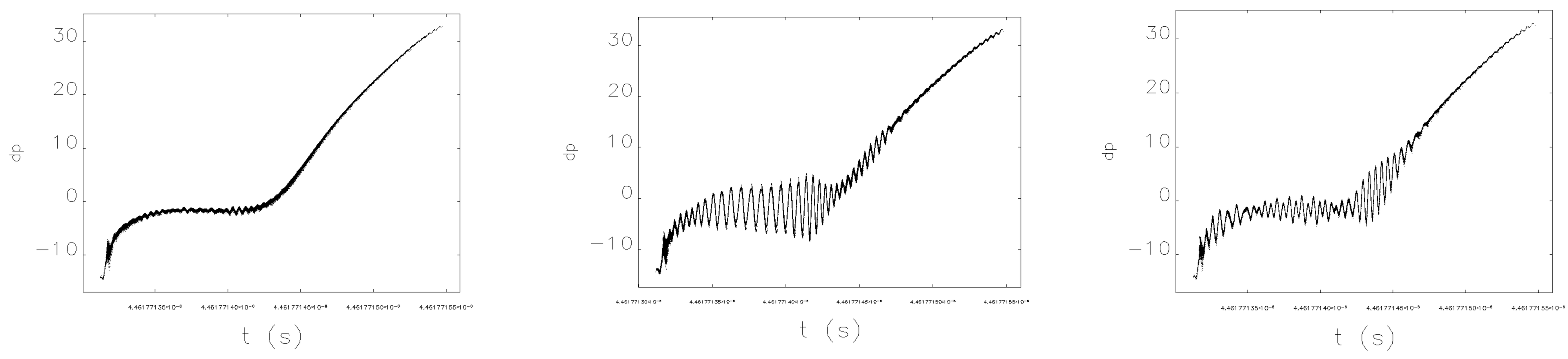

Figure 3. Longitudinal phase space of the beam at the exit of SHINE linac, with (a) 60 μm, (b) 120 μm, (d) 150 μm initial density modulation

Conclusion

The study of microbunching instability of SHINE linac has been carried out with the lattice design up-to-date. The results show that the analytical estimation is reasonably consisted with the numerical simulation, which provides us the information about the range of the initial modulation wavelength that should be avoided when operating the machine. Further investigations with laser heater included is needed to reveal the suppression effects for various modulation wavelength.

References

[1] Y. Wang and M. Borland, Pelegant: A Parallel Accelerator Simulation Code for Electron Generation and Tracking, AIP Conf. Proc. 877, 241 (2006).

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[3] Z. Huang, M. Borland, P. Emma, J. Wu, C. Limborg, G. Stupakov, and J. Welch, Suppression of microbunching instability in the linac coherent light source, Phys. Rev. ST Accel. Beams 7, 074401 (2004).