Study of Microbunching Instability: mechanism of growth and suppression

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Abstract

Mechanism of growth of the microbunching instability (MBI) has been analytically studied [1] and simulated with the Elegant tracking code [2]. Longitudinal space charge (LSC) and statistical noise in the particle distribution have been considered as sources of the instability, amplified by coherent synchrotron radiation (CSR) in a scheme of double compression of the electron beam. A laser heater has been included in the simulations in order to suppress the instability through Landau damping. Final results have been applied to the present layout of the Fermi@Elettra project [3].

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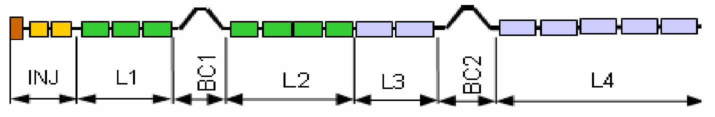
Schematic layout of a 1.2 GeV linac for the supply of a high quality electron beam of reduced beam sizes for free electron laser.



GROWTH

LSC: it is driven by high charge density. It modulates the beam energy and spatial distribution.

$$\lambda \geq \lambda_{LSC} \text{ (set by user) are enhanced}$$

CSR: it is synchrotron radiation emitted in the chicanes at wavelengths comparable with the beam length. Tailing electrons emit radiation that hurts leading electrons.

CURRENT SPIKES: they emit CSR and originate from:
(i) statistical noise in the particle distribution;
(ii) spatial modulation generated by LSC;

MBI: CSR enhances the beam energy modulation which transforms again into spatial modulation, providing the growth of the modulation amplitude.

SUPPRESSION

LANDAU DAMPING: energy modulation by MBI may be damped increasing the uncorrelated momentum spread of the electron beam (i.e., the thickness of the beam phase space in Figure 2) just over the modulation amplitude. Thus, the amplitude cannot grow anymore and the instability is suppressed.

$$\lambda \leq \lambda_{\gamma} = \frac{(2\pi \times R_{56} \times \sigma_{\delta,uncorr})}{(1 + h \times R_{56})} \quad \text{are suppressed}$$

LASER HEATER: it is included in the linac in order to increase the uncorrelated energy spread. Laser heater consists essentially of an undulator in which the electron beam interacts with the electromagnetic radiation, so increasing the momentum spread by the desired amount.

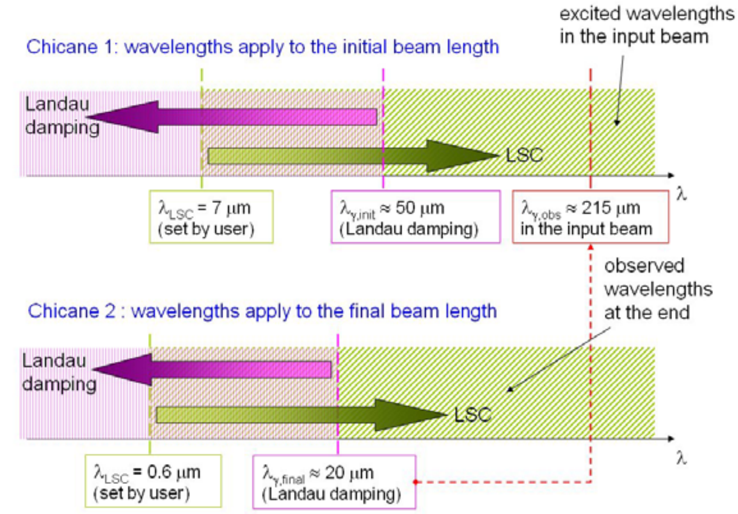


Figure 1. Growth and suppression of MBI in the 1st and 2nd chicane.

- λ_{LSC} is the *minimum* wavelength amplified by LSC.
- λ_{γ} is the *maximum* wavelength suppressed by Landau damping.
- $\lambda \geq \lambda_{\gamma}$ will be enhanced by LSC after the compression.

⇓

After the 2nd chicane only $\lambda \geq 20$ μm can be amplified by MBI. They correspond to perturbations in the initial distributions (uncompressed beam) of wavelengths $\lambda_{\gamma,final}$ times the total compression factor 10.5, that is $\lambda_{\gamma,obs} = 215$ μm in the input beam.

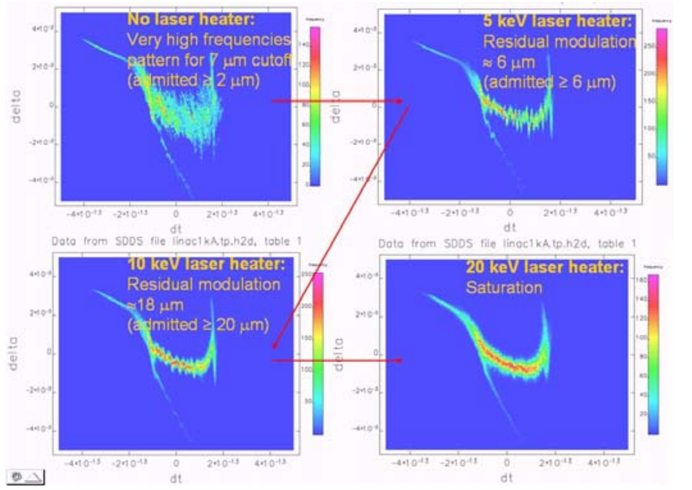


Figure 2. Contour plots of the longitudinal phase space; Elegant tracking at the end of linac.

- As energy spread provided by laser heater increases, suppression of MBI covers longer wavelengths of modulation.
- Spectral analysis applied to the tracking output agrees with theoretical predictions.
- 20 keV rms laser heater are sufficient to damp completely the instability, but they provide a final uncorrelated energy spread of about 200 keV.

Parameter	Value	Unit
Bunch charge	330	pC
Bunch duration (full width)	6	Ps
Peak current	75	A
Uncorrelated energy spread	3	keV
Laser heater energy spread (rms)	8	keV
Normalised emittance (rms)	0.8	μm
Compression factor in 1st chicane	3.5	
Compression factor in 2nd chicane	3.0	
Beam final energy	1.2	GeV
Bunch duration (full width)	0.5	ps
Peak current	900	A
Slice energy spread (rms)	130	keV
Normalised emittance (rms)	0.9	μm

Table 1. Parameters of beam dynamics (input in the upper table, final in the bottom)

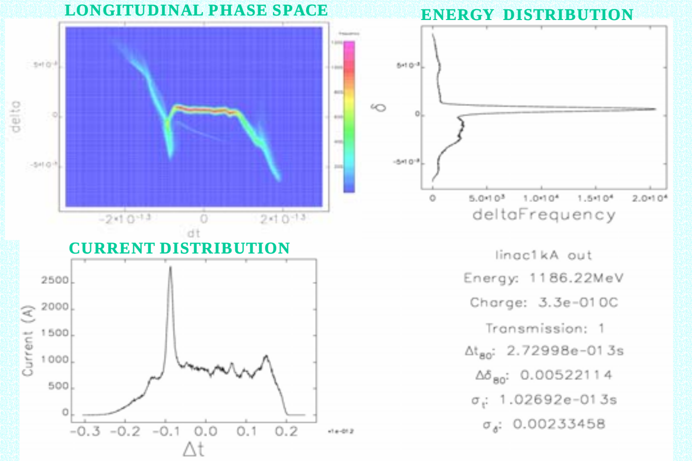


Figure 3. Longitudinal phase space, energy and current distributions. CSR and 8 keV rms from the laser heater are taken into account. Elegant tracking with 1 million macroparticles.

REFERENCES
1. Huang Z. *et al.*, *Phys. Rev. ST-AB*, **7**, 074401 (2004).
2. Borland M., APS LS-207 (2000).
3. Bocchetta C. J. *et al.*, FEL2005 (2005).