STUDIES OF MICROBUNCHING AT BNL NSLS SOURCE DEVELOPMENT LABORATORY *

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Abstract

In this paper we report the current status of the studies of a phenomenon of microbunching at NSLS Source Development Laboratory (SDL). We observed the microbunching inside 70MeV electron bunches even for subpicosecond beams of 10pC charge. Additional microbunching is formed when the beam is compressed in the bunch compressor utilizing the 4-magnet chicane. We study the mechanisms of microbunching in an electron beam generated by a 100fs laser pulse. It allows reducing the possibility of having beam structures induced by photo-injector laser, eliminating effects of RF curvature, and enhancing the longitudinal space charge (LSC) and the coherent synchrotron radiation (CSR) effects.

INTRODUCTION

The formation of longitudinal substructures inside the electron beam, so-called microbunching, has been observed in a number of facilities [1-3]. The microbunching could be detrimental to FEL performance. At the present time the mechanisms of microbunching are not well understood, and the recipes for curing it are intensely discussed [4].

The microbunching was observed [5] at the NSLS SDL [6]. Recently a dedicated program for detailed studies of the physics underlying microbunching at SDL has been developed.

In SDL the electron beam generated in photocathode RF gun is accelerated to 70MeV, and compressed in the bunch compressor (BC) consisting of the linac section, which introduces correlated energy spread, and the four-bend chicane which produces relevant momentum compaction. The BC is followed by three linac sections capable of accelerating electron beam up to 300MeV. Fully accelerated beam is fed to the 10m long undulator to produce coherent radiation from IR to XUV. The SDL beamline is equipped with a spectrometer magnet located downstream of the BC, followed by a beam profile monitor (BPM). The SDL layout is schematically shown in Figure 1.

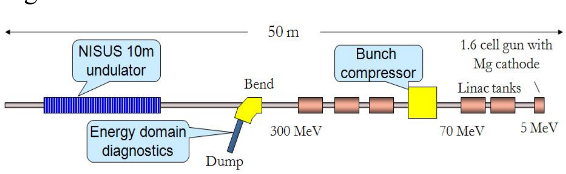

Figure 1: The SDL layout.

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SELF-INDUCED BEAM STRUCTURES INSIDE SUBPICOSECOND PULSES

We studied the mechanisms of microbunching development for the electron bunches with charges up to 100pC generated by 100fs laser pulses. The projected peak current of 100pC beam at 70MeV is 1kA, but due to the space charge lengthening of the beam at low energy, only 300A peak current was achieved for 100pC beam. Using the short pulses practically eliminates the possibility of laser-induced longitudinal beam structures. It also eliminates effects of RF curvature. The LSC effects at the low beam energy, as well as CSR effects in the BC chicane are enhanced for the shorter pulse.

LSC-induced Modulation of Longitudinal Phase Space

For the sake of consistency we first turned the chicane off, thereby eliminating any possible CSR effects on the beam. We also switched off the last three linac sections, and explored the longitudinal phase space of 70MeV beam. Thus, any longitudinal microbunching observed inside the 100fs bunch can be developed through LSC effect only.

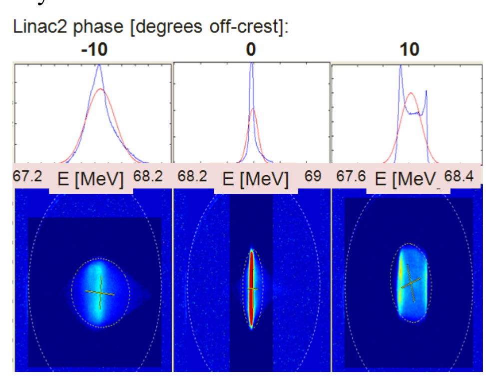

Figure 2: The scan of Linac2 phase. Lower plots are beam images on the BPM. Upper are energy projections (blue), and Gaussian fits (red).

As the phase of the second linac section (Linac2) was scanned +10 and -10 degrees off-crest, the projection of beam's longitudinal phase space on energy axis was observed with the BPM downstream of the spectrometer bend. For the on-crest setting of Linac2 the beam has a pseudo-Gaussian shape in energy domain. Negative chirp fattens the beam projection on the energy axis, keeping the shape the same. When the beam is positively chirped, the formation of a two-hump structure in energy domain is observed. Results of such scan for 100fs 100pC beam are presented in Figure 2.

We also recorded the beam profiles on the spectrometer BPM at on-crest phase of Linac2, setting the third linac section (Linac3) to "positive" and "negative" zero-crossing phase. This is a zero-phasing technique used for bunch length measurements as described in [7]; in our case the results of its application to 100fs 100pC beam are shown in Figure 3.

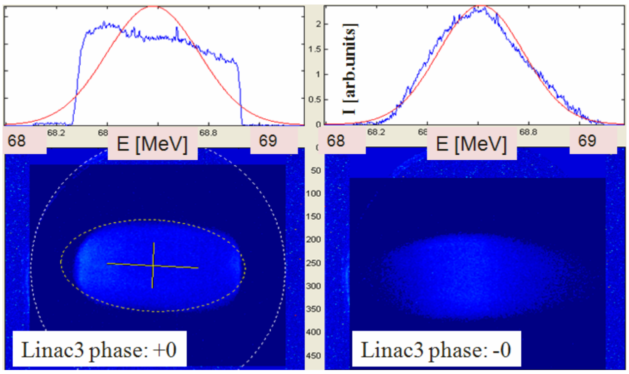

Figure 3: Zero-phasing with Linac3. Lower plots are beam images on the BPM. Upper are energy projections (blue), and Gaussian fits (red).

There is an obvious asymmetry in the shape of beam projections between positive and negative off-crest phases of Linac2 and between positive and negative 0-phases of Linac3. Such an asymmetry shows that observed "substructures" are a result of energy modulation of the longitudinal phase space rather than real individual beamlets in time domain. Indeed, the tomography-like reconstruction of the beam's longitudinal phase space at the entrance of Linac2 reveals the energy modulation of the beam. Results of beam reconstruction are presented in figures 4 and 5. One can see that there are no beamlets in the reconstructed distribution. When such beam is chirped, the pseudo-structures in energy domain are produced because of energy modulation.

The effect of LSC on the beam was simulated using PARMELA. The beam was tracked from the photocathode to the entrance of Linac2. It was found that the simulated beam has the same energy modulation amplitude that was observed in the experiment.

Figure 6 shows the measured and simulated energy modulation for 100fs beams of different charges.

CSR-induced Microbunching

When the chicane is turned on to its nominal setting of R_{56}=4.3cm and Linac2 phase is set at -20 degrees off-crest, the formation of additional substructures in the energy domain is observed (Fig. 7). Such chicane and Linac2 settings generate under-compressed beam. There is a possibility that the 4-hump distribution observed in energy domain is not due to CSR effect.

In that scenario the BC would rotate phase space so that the energy modulation turns into longitudinal density modulation. Next, the two-humped charge distribution would modulate energy with double "frequency" through the LSC. Such potential mechanism of additional beam structure development is discussed in details in [4].

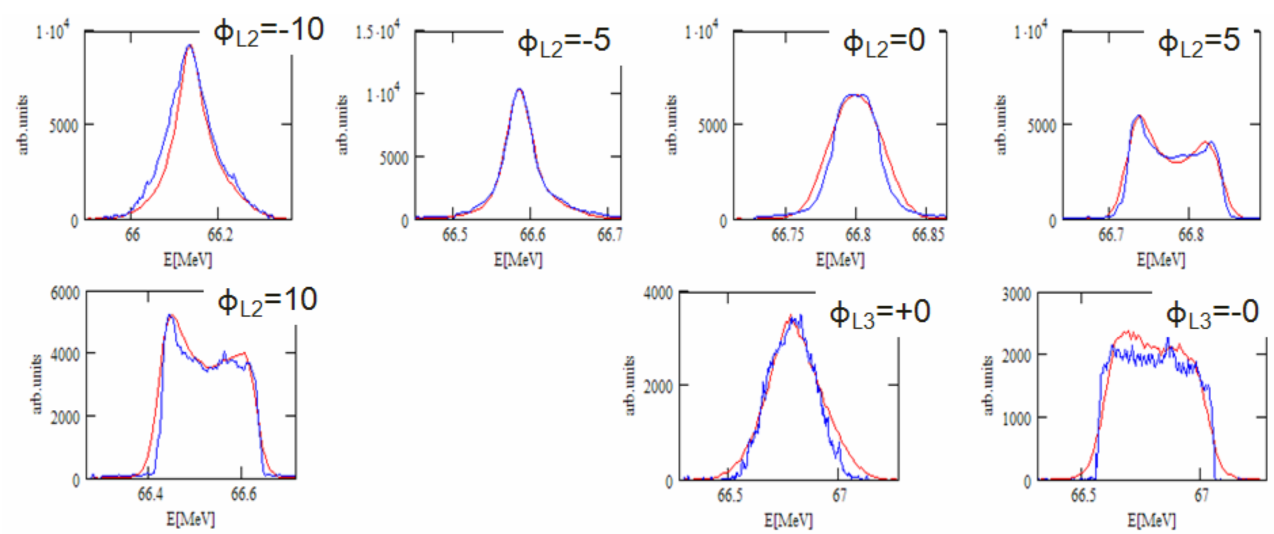

Figure 4: Simplified tomography. Blue traces represent measured 50pC beam projections on energy axis for Linac2 scan (first 5 plots) and for Linac3 zero-phasing (2 last plots); measured projections are fit (red) with simulated beam distribution shown in Fig. 5.

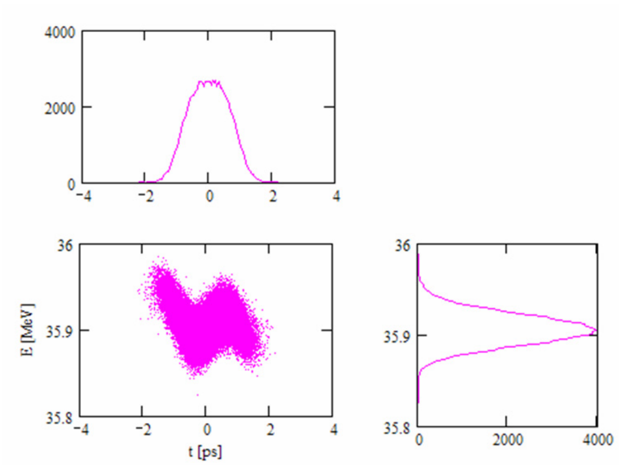

Figure 5: Beam's longitudinal phase space at the entrance of Linac2 reconstructed with simplified tomography. Chirping this distribution produces pseudo-structures in energy domain.

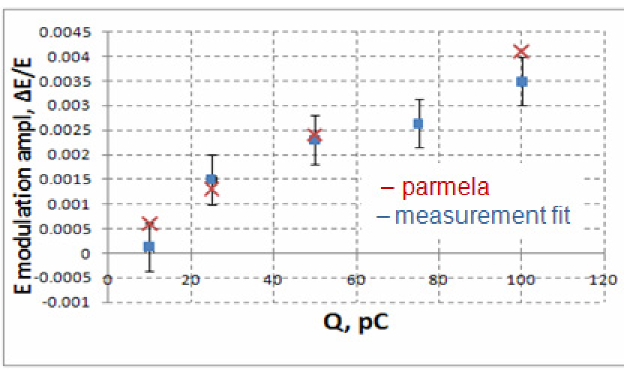

Figure 6: Measured (blue) and PARMELA simulated (red) energy modulation of 100fs, 10pC-100pC beam.

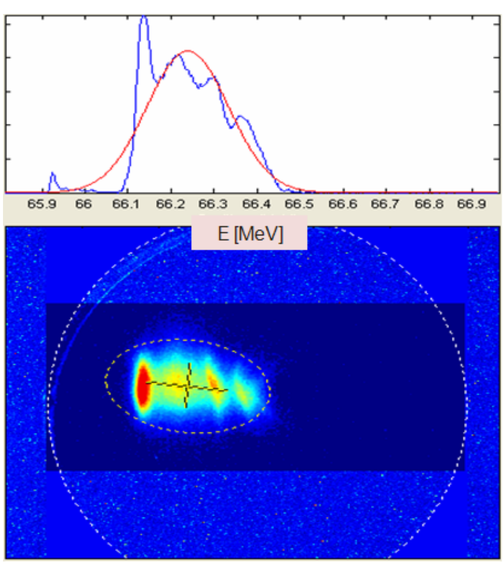

Figure 7: Beam substructures at nominal chicane settings and -20deg off-crest Linac2 phase. Lower plot is beam image on the BPM. Upper is energy projection.

It can be shown that 4-hump energy projection can be developed through BC gymnastics topped with LSC effect only if LSC provides double-frequency energy modulation of high amplitude. On the other hand, detailed beam tracking of the reconstructed beam distribution through the BC down to the spectrometer shows very weak LSC effect, since the beam is essentially relativistic downstream of the first linac section.

From these considerations we conclude that additional substructures observed in the compressed beam are the real beam breakups in the time domain produced by CSR.

CONCLUSION

Consistent studies of microbunching effect at SDL showed that in the absence of beam compression the pseudo-structures observed in the energy domain are caused by LSC-induced energy modulations. It was shown that in the absence of both CSR and laser-induced substructures the beam does experience "macrobunching" rather than microbunching. Real microbunching, i.e. beam breakups in time domain, is essentially related to CSR.

We plan to continue studies of the formation of CSR-induced structures for different bunch lengths and charges. We also plan to study both LSC-caused and CSR-caused microbunching in the beams with controlled laser-induces substructures by implementing laser pulse shaping.

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