EXPERIMENTS IN COHERENT RADIATION AT SDL

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Abstract

The Source Development Lab at NSLS consists of a S-band photoinjector with Ti:Sapphire drive laser, 200 MeV linac, chicane bunch compressor, and 10 m long NISUS undulator. Experiments are underway to measure and understand the emission of intense, coherent infrared radiation and accompanying microbunching structure observed on the electron beam during pulse compression. Results are reported for measured radiation power, electron beam energy and time profiles, and comparisons are made with recently developed coherent synchrotron radiation (CSR) instability theory.

1 INTRODUCTION

The DUV–FEL linac at SDL is dedicated for research with a high brightness electron beam source [1] and an FEL program using High Gain Harmonic Generation [2]. A magnetic chicane bunch compressor is used to compress the electron beam from several picoseconds duration to less that 1 ps, amplifying the peak electron beam current from tens to hundreds of amperes. As the electron bunch becomes shorter, the relatively weak incoherent radiation emitted as either synchrotron light in the magnetic bends, wakefields in the vacuum chamber, or transition radiation as it traverses different materials can become coherent at wavelengths comparable to features on the electron bunch. The light intensity is then enhanced by the number of electrons, a factor of 10^9, raising peak power to the level of hundreds of megawatts. The strong radiation may interact further with the electrons, causing modulations in their energy or time distributions. If the radiation is emitted in a dispersive region such as the chicane, then the beam trajectories will be altered and the transverse emittance will effectively grow.

2 EMITTANCE GROWTH IN BUNCH COMPRESSION

Temporal profiles of the compressed beam were measured using the zero–phasing method [3, 4], and emittance was measured in the straight downstream of the chicane using the quadrupole scan method. The measured peak current and the normalized emittance are shown in Fig. 1. The peak current values are averages of both zero phases of the accelerating electric field, and the error bar denotes the difference between the two. At high compression there is still substantial energy chirp entering the zero phasing section,

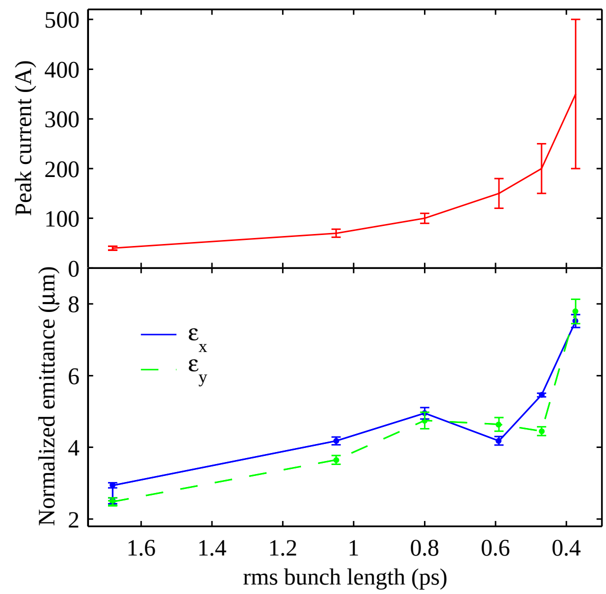

Figure 1: Emittance for different compression factors. The upper part shows the peak current and the lower part the normalized emittance as a function of bunch length.

Table 1: Parameters for the SDL electron beam and compressor.

Uncompressed beam current	40–60 A
Compressed beam current	200–600 A
Uncompressed pulse length	1.2 ps RMS
Compressed pulse length	0.3 ps RMS
Estimated local energy spread	2.0E-5 RMS
Normalized slice emittance	2.0 μm
Beta function at chicane	5 m
Charge	50–300 pC
Energy at compression	70.0 MeV
Chicane bend angle	0–14 degrees
Dipole length	19 cm
R56	0–10 cm

so that results from the two RF slopes differ considerably. The horizontal emittance growth can be attributed to non-cancellation of the dispersion in the chicane due to CSR emission, but the vertical emittance growth is not yet well understood.

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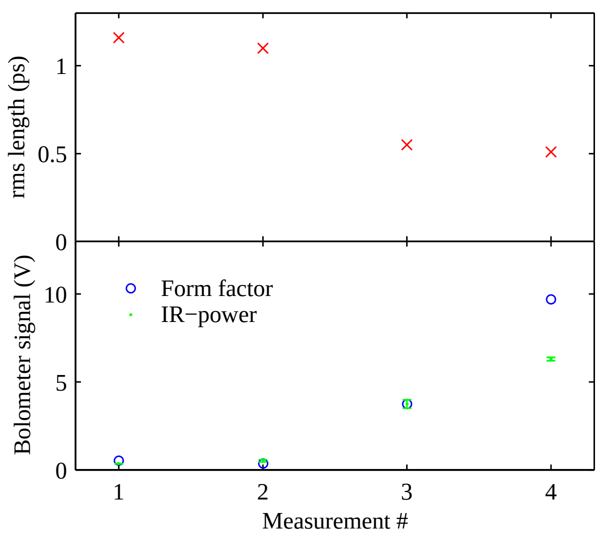

Figure 2: TOP: rms bunch length from zero–phasing measurement for 4 different accelerator and chicane settings. BOTTOM: measured IR power and integrated bunch form factor from zero–phasing measurement.

3 COHERENT RADIATION MEASUREMENT

The infrared power is measured with a LHe-cooled bolometer at a port about 6 m downstream from the chicane [5]. An intercepting mirror is inserted into the beam to couple the radiation into a copper pipe waveguide to the detector. Fig. 2 shows measurements at four different accelerator settings for bunch temporal profiles and radiation power. Measurement # 1 has the chicane off and the beam accelerated on crest in tank 2. In measurements # 2 to 4 the chicane is powered with 50 A and the tank 2 phase is still on crest, -20 deg, and -26 deg, respectively. The bolometer was mildly saturated at the 4th setting. The radiation source is most likely transition radiation from the mirror, but it can include contributions from CSR emitted in the chicane and wakes in the linac and beampipes upstream. The bunch form factors shown in the figure are calculated from the temporal profiles and integrated over the spectral range of the bolometer. They are further normalized to the IR power of the 3rd setting and show good agreement with the bolometer data.

4 MEASUREMENT OF BEAM MODULATION

The images from the zero–phasing measurement of the last section reveal microbunching in the compressed beam images as shown in Fig. 3. The upper image is the uncompressed beam and the lower shows a medium compressed beam. Both profiles are shown in Fig. 4 together with the time profile of the UV–laser. This profile was obtained by a difference frequency crosscorrelation in BBO between the UV–laser and the Ti:Sapphire–Oscillator with a temporal

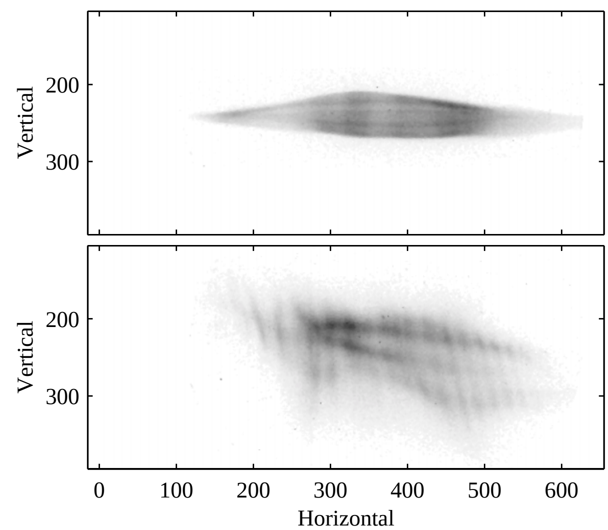

Figure 3: Scintillator screen images of umcompressed (upper) and compressed (lower) beam.

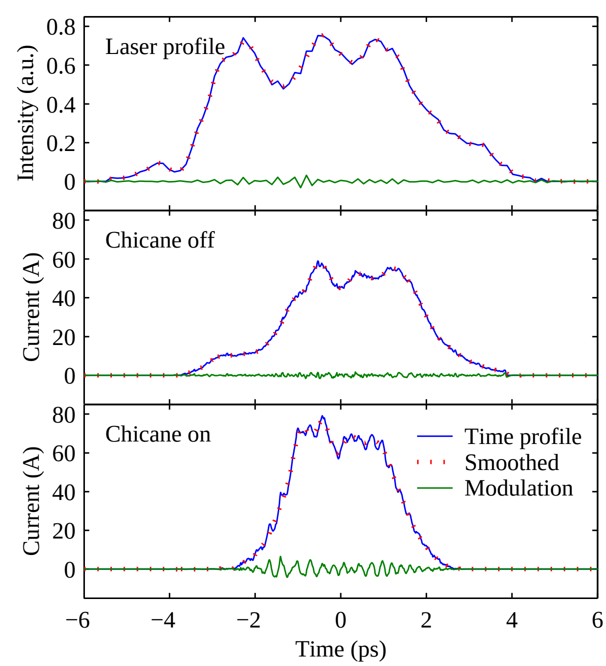

Figure 4: Time profiles of laser, uncompressed, and compressed electron beam.

resolution of 300 fs and represents the laser beam used in this experiment. The rms bunch length of the profiles is 1.9, 1.4 and 0.95 ps, respectively. The head of the bunch is always to the right. The different bunch lengths of laser and uncompressed beam are due to ballistic compression in the gun and the low energy part of the linac. To extract the modulation in the beam, smoothed profiles were generated by fourier filtering above 80 cm^{-1} and are also shown in the figure together with the modulating part taken from the high frequency components only.

The bunch form factors of all profiles are shown in

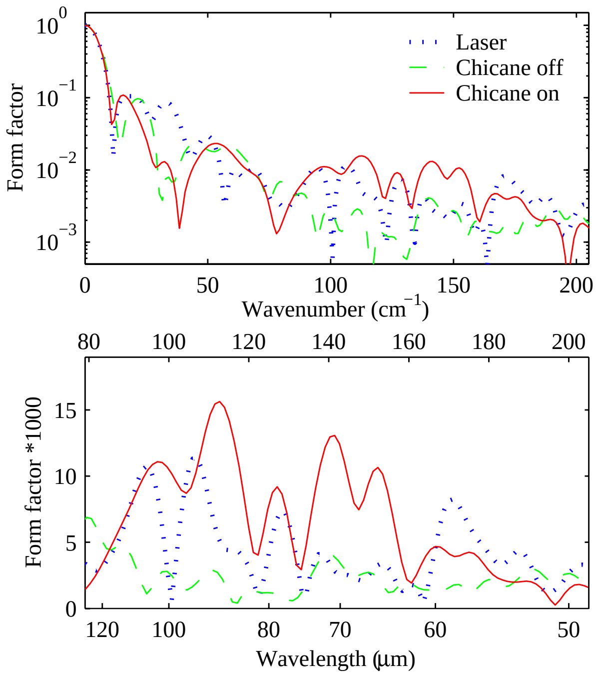

Figure 5: Bunch form factor of time profiles from Fig. 4.

Fig. 5. The frequency scale of the laser and uncompressed beam spectra are rescaled with the respective compression factors of 2 and 1.5 to match spectral structures of the compressed beam. As can be seen in the lower part of the figure, there is an enhancement of bunch modulation in the 80 to 200 cm^{-1} or 125 to 50 μm range. The spectrum of the laser profile in this spectral range is near its noise level, but still below the spectral power of the compressed beam.

Similar modulations are present in nearly all time profiles of the electron beam at SDL after compression, but not generally in the uncompressed beams. Possible sources of the modulation are unresolved temporal structure in the laser pulse, surface roughness wakes in the small diameter beam pipe just upstream of the IR port, or growth of a CSR instability in the chicane, which is discussed next.

5 CALCULATION OF CSR INSTABILITY

The microbunching instability in a chicane bunch compressor has recently been described by an analytical model [6]. With this model, the amplification of a density modulation much smaller than the length of the bunch can be calculated. The model assumes a longitudinally uniform charge distribution including incoherent energy spread and finite transverse emittance. For these experiments the quadrupole triplet that matches into the chicane was off, and the beta function at the chicane was relatively large at 5 m.

The electron beam parameters used in the calculation are as follows: Bunch charge 200 pC, beam energy 70 MeV, uncompressed peak current 50 A, uncorrelated energy spread 2×10^{-5}, and slice emittance of either 2μm or

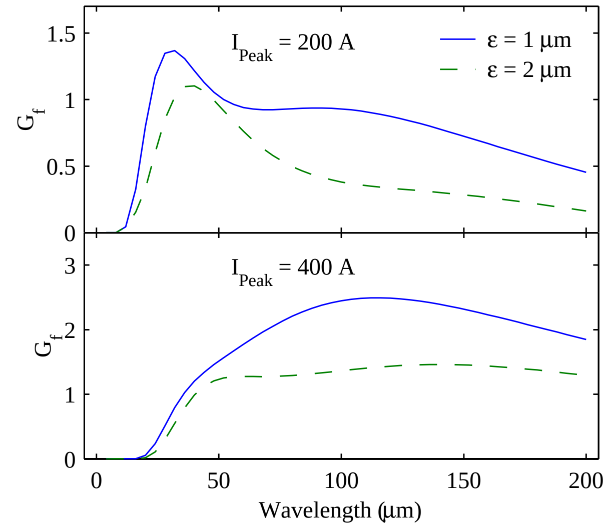

Figure 6: CSR instability gain for SDL chicane. The wavelength corresponds to a modulation at the chicane entrance.

1μm. The initial energy chirp is set to result in a compression factor of 4 and 8 giving peak currents after compression of 200 and 400 A, respectively. The calculations shown in Fig. 6 exhibit a gain factor which is larger than unity, indicating mild growth of initial modulations at these frequencies. The experimentally observed beam modulations are present also when the emittance is larger and the peak current is lower than the simulated values, but the simulations indicate no growth for these cases, so that some uncertainty remains as to the cause of the observations. Upcoming studies will measure the IR spectrum as well as total power, and the electron beam's slice emittance for varying amounts of compression.

6 ACKNOWLEDGEMENTS

The authors wish to thank G. Stupakov for providing the mathematica code to calculate the CSR instability.

7 REFERENCES

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