"JITTER FREE" FEL PULSES FOR PUMP AND PROBE EXPERIMENTS*

R. Follath, A. Meseck †,G. Wüstefeld
BESSY GmbH, Berlin, Germany

Abstract

The cascaded high-gain harmonic generation (HGHG) scheme proposed for the BESSY-FEL contains an inherent potential for providing jitter free radiation pulses for pump and probe experiments. In an HGHG stage an energy modulation is imprinted to the electron beam by a seeding radiation. A dispersive section converts this energy modulation to a spatial modulation which is optimized for a particular harmonic. The subsequent radiator is optimized for this harmonics and generates radiation with high power which is used as seeding radiation for the next stage. After passage through the modulator, the seeding radiation become redundant and can be separated from the prebunched electrons using a deflecting dispersive chicane. This radiation and the final FEL output will have a fixed temporal separation as the first one is the driving seeding radiation for the second one. Using the planned demonstration facility for HGHG scheme at BESSY as an example, we present simulation studies for a sequences of two jitter free pump and probe pulses including the deflecting chicane and a suitable beam line.

INTRODUCTION

High power, short pulse length and full coherence are the main parameters of the second generation free electron lasers. To provide radiation with these properties in the VUV and soft X-ray regime, BESSY plans to build a seeded FEL facility based on high-gain harmonic generation scheme [1, 2]. This scheme uses cascaded stages each consisting of undulator/dispersive chicane/undulator section to up-convert the seeding frequency.

The technical design report of the BESSY Soft X-ray FEL facility [3] was evaluated by the German Science Council and recommended for funding subject to the condition that it's key technology, the cascaded HGHG scheme, be demonstrated beforehand. To address this issue, BESSY is proposing the proof-of-principle facility STARS [5] for a two-stage HGHG cascade which will serve as a user facility even after the commissioning of the BESSY FEL. The STARS is seeded by a tunable laser covering the spectral range of 700 nm to 900 nm. The target wavelength ranges from 70 nm to 40 nm with peak powers up to a few hunderd MWs and pulse lengths less than 20 fs (rms). The polarization of the fully coherent radiation will be variable. For efficient lasing a 325 MeV driver linac is required. It consists of a normal-conducting gun, superconducting TESLA-type modules modified for CW operation and a bunch compressor.

The separation of the seeding radiation and prebunched electron beam after the modulator, i.e. in the dispersive chicane section, offers the possibility to use the now redundant seeding radiation for experimental purposes. While the prebunched electron beam will generate high power coherent radiation passing through the following radiator. The redundant seeding radiation and the radiator output will have a jitter-free time lag as the first one is the driving radiation for the second one, and thus they offer the possibility of jitter free pump and probe experiments.

In principle, the separation can take place before, inside or after the dispersive chicane, but it has not to affect the spatial modulation, as the quality of the radiator output depends strongly on the quality of the frequency upconversion procedure, which again depends on the quality of the spatial modulation (bunching). Also other effects like residual dispersion, coupling or increased beam size have to be avoided. Generally, the dispersion strength, which is necessary to convert the energy modulation to the spatial modulation, is not high. Hence the bump amplitudes are not large enough to install mirrors or other optical elements to deflect the radiation. A separation of the radiation and electrons can only take place by an additional bending of the electron beam. A simple bending, with an additional dipole or due to a mismatch of the four bump dipoles, causes residual dispersion, coupling between transverse and longitudinal motion and spoils the bunching. Thus it deteriorates the radiator output strongly. However a proper deflection can be introduce via deflecting dispersive chicane [4].

To provide FEL pulses for pump and probe experiments, a suitable beam line to guide the pulses to the experimental stations has to be designed. Further, it is advantageous to design the beam line with a tunable time delay between both pulses, as the time lag from the FEL line is determined by the constraints of the fresh bunch technique [2] and is thus rather fixed. In this paper, we present simulations of two jitter free pulses using suitable designs of the deflecting chicane and the beam line for the STARS facility.

DEFLECTING DISPERSIVE CHICANE IN STARS

The demonstration facility STARS will consist of two HGHG-stages fed by a 325 MeV driver linac. Figure 1 shows a schematic view of the FEL line. For more details of the STARS facility see please [5].

For the presented simulation we assume an electron

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† meseck.at.bessy.de

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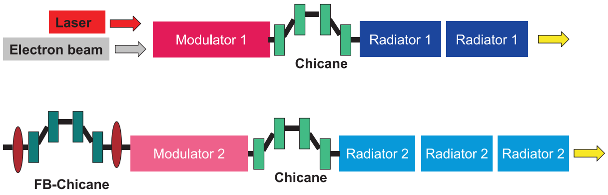

Figure 1: A schematic view of the FEL line of the STARS facility with simple dispersive chicanes.

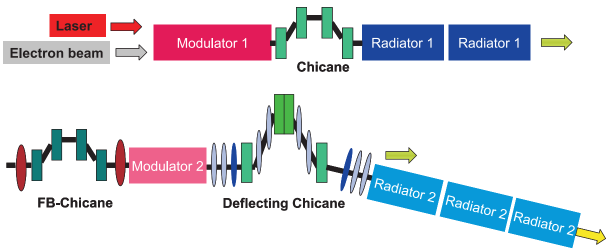

Figure 2: A schematic view of the FEL line of the STARS facility with a deflecting chicane.

beam with a peak current of 500 A, transverse normalized slice emittances of 1 mm mrad and an rms energy spread of 10 keV. The deflecting dispersive chicane was placed after the second modulator. In this scenario the output of the first radiator, after modulating the electron energies, together with the output of the second radiator will be guided to the experiment. Figure 2 shows the FEL line of the STARS with the deflecting chicane.

Compared to the chicane introduced in [4], the present chicane is slightly modified to fit to the STARS purposes. The total length of the chicane amounts to 4 m instead of 10 m in [4]. It consists of two dipole families and two quadrupoles, tuned as an achromatic bend with variable m_{56} value. The m_{56} is a key parameter to describe the spatial modulation which results when the energy modulated beam passes through a dispersive chicane. The integrated dipole fields are kept constant to define the deflection angle of 100 mrad. The bending radius of the dipole families amounts to 10 m. The lengths of the Dipoles differs and thus cause different deflecting angles. One family is excited opposite to the other one, the difference between the integrated fields of both families in combination with the excitation of the quarupoles yields the value of m_{56}. The quadrupoles tune the dispersion outside of the chicane to zero. At the entrance and exit side of the chicane an optical matching section is required, consisting of three quadrupoles on each side. For the full optical line m_{56} has the same tuning as for the simple bump. As discussed in [4] the transverse beam amplitudes and the accumulated spread in chromatic phase errors stay sufficiently small to design the chicane without higher-order corrector magnets. The deflecting angle of 100 mrad translates in ca. 20 cm offset at the end of the chicane section. This a comfortable distance for the radiation to direct past the

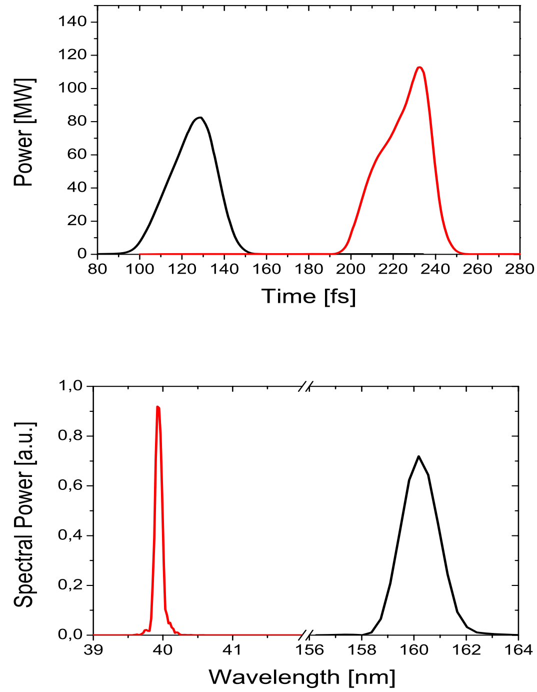

Figure 3: Temporal (top) and spectral (bottom) profile of the radiator outputs. The output of the second radiator (red line) is extracted after the first module. The first radiator's output (black line) is extracted after the second modulator.

subsequent radiator. Using the code GENESIS 1.3 [6] in time-dependent mode, the simulation has been done for the shortest FEL wavelength of 40 nm, as in this case the radiator outputs are most sensitive to electron beam deviations. In this configuration the wavelength of the first radiator's output amounts to 160 nm which is the fifth harmonic of the laser seed of 800 nm. The second radiator is tuned to the fourth harmonic and delivers radiation at the desired wavelength of 40 nm. In the chicane a m_{56} of 26 μm is required to convert the energy modulation into the optimal bunching at the entrance of the second radiator. The saturation length is about 3.3 m which is the end of the first module of the second radiator. The gap of the following two radiator modules are assumed to be open, thus there is no further interaction after the saturation.

Figure 3 pictures the temporal and spectral profiles of the output of the first (black line) and second (red line) radiator. The time lag of 100 fs generated in the fresh bunch chicane, corresponds to a pulse separation of 6 rms pulse width. It ensures that a fresh part of the bunch is seeded in the second modulator.

BEAMLINE

The first radiator emits 2 μJ-pulses at 160 nm wavelength with a pulse length of 30 fs. The radiation with a divergence of 200 μrad (rms) is deflected and collimated by the toroidal mirror M4. The paraboloidal mirror M5 de-

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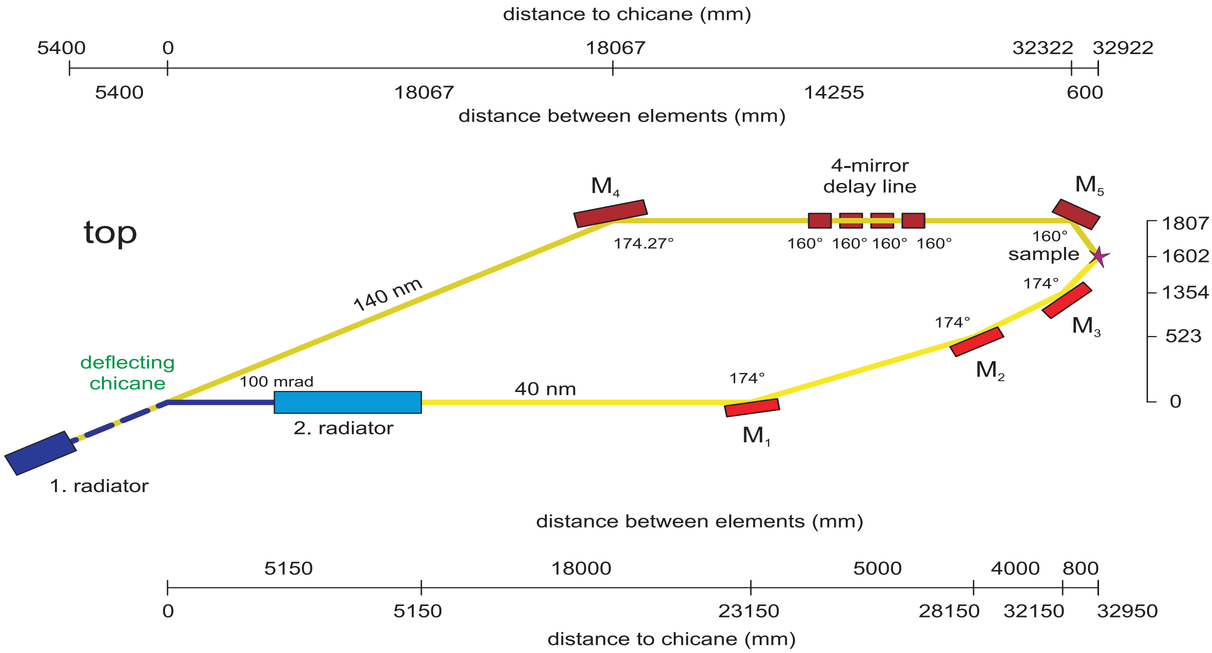

Figure 4: Top view of the optical design for the two color beamline. The lower branch deflects and focuses the 40 nm light emitted by the 2. radiator. The upper branch depicts the 160 nm line. The distances in this branch are given for a setup where the 4-mirror delay line is removed.

magnifies the photon source size of 150 μm(rms) by a nominal factor of 30. With reasonable slope errors ($1-2$ arcsec rms) a focal spot of 20×10 μm^2 (FWHM) can be achieved.

The second radiator emits pulses at 40 nm with a pulse energy of 4 μJ and a pulse length of 30 fs (FWHM). Its sources size and divergence are $\sigma = 120$ μm and $\sigma' = 22$ μrad, respectively. The 40 nm light is deflected by the plane mirrors M1 and M2 to separate the beam from the adjacent monochromatic beamline. The toroidal mirror M3 demagnifies the source nominally by a factor of 34. With reasonable slope errors a focal spot with the same dimensions as in the 160 nm line can be achieved. The focal lengths of both focusing mirrors (M3 and M5) are 800 mm and 600 mm, respectively. This preserves enough space for even larger experimental stations. The optical path along the 160 nm branch is 28 mm shorter than the corresponding in the 40 nm branch. An additional four mirror delay line consisting of four plane mirrors with deflection angles of $160°$ is used to introduce an additional, variable, path extension between 10 and 50 mm in the 160 nm line.

Carbon coated mirrors in the 40 nm line transmit 40% of the incident power to the experiment. The transmission of the six Rhodium coated mirrors in the 160 nm line is approximately 40%. This may be improved by a factor of two by proper dielectric coatings.

CONCLUSION

The inherent potential of the HGHG scheme for providing pulses with jitter free time lag is elaborated using the layout of the STARS facility as an example. Obviously the frequencies of the pump and the probe pulse are related via chosen harmonic number in the second stage. However using the time delay in the beam line, the jitter free time lag of the pulses becomes variable. It does no longer depend on the fresh bunch chicane. Pulse energies around 1 μJ can be expected at experimental station as the transmission through the beam line is about 40% for both wavelength. Due to the large bending radii in the deflecting chicane and the low peak current of the beam, the CSR effects are assumed to be negligible for this study. Nevertheless, further investigation on CSR effects and also on electron optics tolerances are necessary in order to ensure that the radiator output does not suffer.

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