CONSIDERATIONS FOR DOUBLE PULSE LASING FROM THE BESSY-FEL[*]

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Abstract

BESSY proposes a linac-based High-Gain Harmonic-Generation (HGHG) free electron laser (FEL) facility with three independent FEL lines [1]. High efficiency of the FEL process is ensured as the seed radiation interacts only with unperturbed parts of the electron bunch in every HGHG-stage. However, simulations show that bunch parts that have previously lased generate a noticeable radiation power level in the final amplifiers. This motivated simulation studies on the significance and intensity of such inherent additional pulses. It is revealed that the BESSY-FEL provides the opportunity to deliver multiple pulses at the FEL exit with peak powers in the MW- as well as double pulses in the GW-range. This might be of high interest to the user community.

INTRODUCTION

A seeded FEL in the VUV-range depends on the quality of down-conversion of a commercially available input seed laser to the desired output wavelength range well below 100 nm. Higher harmonics of the electron beam spatial density distribution are used to initiate intense and coherent harmonic radiation.

The BESSY Soft X-ray FEL uses a cascade of two to four stages to down-convert the initial seed wavelength to the desired output wavelength range of 51 nm to 1.24 nm as listed in Table 1. In each stage, seed radiation and electron beam interact in an undulator called modulator where the electron beam is modulated in energy producing a significant $\Delta\gamma/\gamma$. The modulation is converted into spatial bunching in a dispersive section. The bunched beam then enters a second undulator, called radiator, which is tuned to a higher harmonic of the seed frequency. At the end of the radiator, the radiation pulse is extracted to seed a new HGHG stage. Due to the fact that crucial electron beam properties, such as the energy distribution, deteriorate due to the FEL radiation process, the fresh bunch technique is used between two stages [2]. In a magnetic chicane, the electron bunch is bent on a trajectory that delays the bunch relative to the seed radiation. As a result, unperturbed bunch parts will be seeded and brought to lasing in the subsequent FEL stage, enhancing FEL efficiency and improving the properties of the output pulses. The FEL process is brought to saturation in final amplifiers with the same resonant wavelength as the last radiator. As the amplifiers use yet another fresh bunch part with an unperturbed energy distribution, they yield higher FEL effiencies compared to extended radiators.

Table 1: Table of parameters of the BESSY Low-Energy (LE), Medium-Energy (ME) and High-Energy (HE) FEL

	LE-FEL	**ME-FEL**	**HE-FEL**
no. of stages	2	3	4
output wavelength	51-10 nm	12-2 nm	2.4-1.2 nm
peak output power	14-3.5 GW	9-1.5 GW	1.3-1.5 GW

However, since the used parts of the bunch propagate through the remaining structure, they may still contribute to FEL output. In this paper we investigate the influence of lasing from perturbed bunch parts and the extent of the development of additional pulses. Finally, a scheme for the intentional generation of a double FEL pulse is pursued.

LE-FEL Start-to-End Simulations

For the BESSY Low-Energy (LE)-FEL line consisting of two HGHG-stages and an amplifier, complete start-to-end simulations have been carried out with electron bunches tracked from gun through linacs and bunch compressors to FEL undulators [3]. In order to include space charge and CSR effects, ASTRA [4] as well as ELEGANT [5] were used for tracking. For time-dependent simulations of the FEL process and conversion to higher harmonics, GENESIS 1.3 [6] is used.

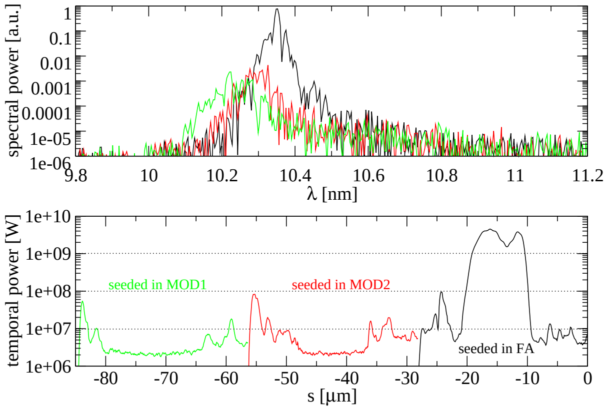

Figure 1: Spectral (top) and temporal (bottom) power distribution of all three bunch parts at end of BESSY LE-FEL.

Figure 1 shows the spectral and temporal power distribution generated at the end of the final amplifier by the suc-

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cessive bunch parts in the LE-FEL. The seeded bunch part arriving first emits up to 5 GW of power while the trailing bunch parts emit less than 10 MW in those parts where they have previously lased. The reason lies in the fresh bunch chicanes that destroy the high degree of bunching achieved in the radiators, see also Figure 3. However, the head and tail of these parts can be observed to develop a certain degree of bunching which is located at the edges of the seed induced energy modulation. There, $\Delta\gamma/\gamma$ is lower and did not match the R56 chosen in the previous dispersive section. As this residual microbunching is then enhanced by the fresh bunch chicane, ultra short pulses with peak powers up to 100 MW are produced. The temporal distance between these peaks is fixed since it is set by the delay time of the fresh bunch chicane. The spectral power of those peaks is roughly two to three orders of magnitude lower than the seeded part. The central wavelength is slightly shifted by about 0.6 nm due to the energy chirp of the bunch.

While the results displayed may not be directly applicable to the user community, they motivated further studies of the effects of residual bunching and lasing from perturbed bunch parts along the FEL. The studies were performed on the BESSY Medium-Energy (ME-)FEL.

RESIDUAL LASING IN THE BESSY MEDIUM-ENERGY FEL

These studies show that in case of the BESSY ME-FEL, the fresh bunch chicanes completely destroy residual bunching prior to the final amplifier because of the short wavelength in combination with the high value of R56.

Influence of the Magnetic Chicane

In order to preserve microbunching until the entrance of the final amplifier, different types of fresh bunch chicanes were studied. In the original setup as detailed in [1], all magnetic chicanes along the undulators consist of a series of four magnets. They are arranged in a C-bend shape with a magnet length of 25 cm and a drift space of 13 cm as depicted in Fig 2, top.

The peak magnetic flux density is set to B=330 mT which provides for a temporal delay of 100 fs. For lower magnetic fields, microbunching can be preserved but the temporal separation between seed and electron beam vanishes. At the nominal field, R56 is in the range of 6e-5 and tends to eliminate microbunching completely. The effect is shown in Fig. 3.

In order to lower R56 and maintain a noticeable temporal separation, an S-bend chicane as depicted in Fig. 2, bottom, was conceived. It could be shown that about 1% microbunching can be conserved if an intermediate quadrupole is incorporated in the chicane design. As a consequence, dispersion is not closed after the chicane and might impair FEL interaction, but it remains at a very low level (0.01 m). As a result, the deteriorated bunch part will again radiate in the final amplifier with an output power in the MW-range, see Fig. 4. However, it has to be noted that the residual pulse as depicted in Fig. 4 will follow after the main pulse, which radiates in the GW power-level. If no intermediate quadrupole is used, bunching is wiped out completely.

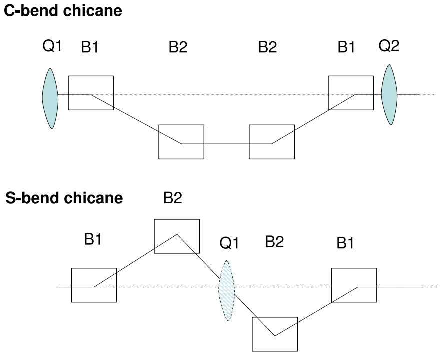

Figure 2: C-bend magnetic chicane, top, as forseen for all dispersive sections along the BESSY Soft X-Ray FEL undulators. Comparison to S-bend chicane, bottom, as a potential scheme for the last fresh-bunch chicanes.

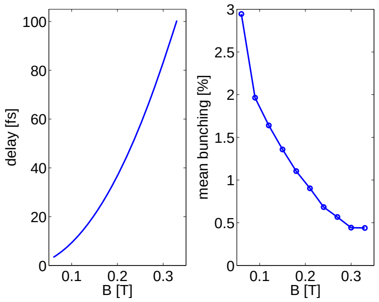

Figure 3: Temporal delay, left, and average residual bunching, right, versus magnetic flux density of magnets in C-bend fresh-bunch chicane prior to BESSY ME-FEL final amplifier.

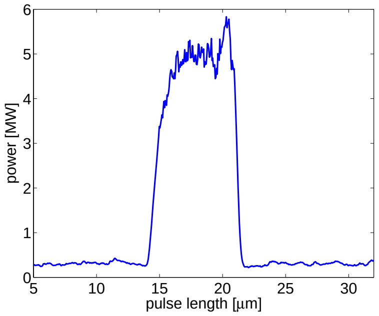

Figure 4: Temporal power distribution of the residual radiation pulse at end of final amplifier when using the S-bend chicane.

DOUBLE PULSE SEEDING OF THE FEL

A thoroughly designed HGHG FEL can also be used to convert two input laser seeds into a high intensity double FEL pulse at a shorter wavelength. In a setup as shown in Fig. 5, the initial seed laser is split up into two pulses by a 50%-transmission mirror. The pulses are then recombined in front of the first undulator. Similar to a simple interferometer, a path length difference can be introduced between the two pulses such that a double pulse with a variable time delay is obtained. The setup allows full variability of the temporal delay as well as the recombination of the initial pulse.

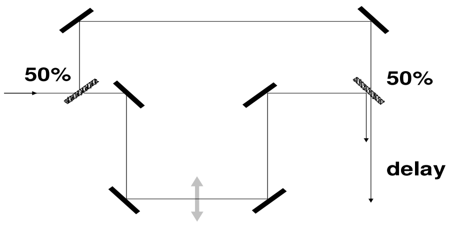

Figure 5: Proposed setup to split the initial seed laser beam up into two pulses for seeding.

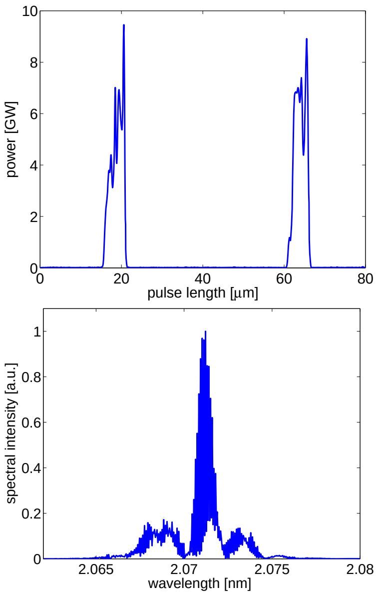

Figure 6: Temporal and spectral power distribution of the FEL pulse at the exit of the final amplifier when seeding with a double pulse of 125 MW peak power.

Time-dependent FEL simulations show that double pulse seeding is well applicable to cascaded HGHG-FELs. In the following simulation example, the BESSY ME-FEL seed laser is split up into two pulses of 100 fs distance and traced through all three stages of the FEL. As the two input pulses now only provide for 25% of the initial intensity, the first modulator was lengthened by 10 periods (from 18 to 28) such that a sufficient degree of energy modulation could be obtained. Figure 6 shows the temporal and spectral power distribution of the double pulse obtained at the end of the ME-FEL final amplifier at 2 nm. The slightly spiky structure of the spectrum originates in the lower signal-to-noise ratio at the beginning of the FEL process.

In order to efficiently operate the FEL with double seed pulses, it has to be ensured that the electron bunch is long enough to provide for high current, high quality bunches to be used in all HGHG stages plus the final amplifier. This is ensure in the case of the BESSY LE- and ME-FEL where the number of total stages including the amplifier does not exceed four. In addition it has to be noted that if the FEL shall be run in double pulse and single pulse mode, overbunching due to the prolonged modulator has to be avoided. This can be done by adjusting the pulse length and peak power of the initial seed laser for the nominal, single pulse, operation.

CONCLUSION

It was shown that fresh-bunch chicanes not only delay the electron bunches relative to the seed radiation but also influence bunching and residual lasing of deteriorated bunch parts. In the BESSY Low Energy FEL at an output wavelength of 10 nm, these residual pulses can be in the order of 100 MW and follow after the main pulse with a fixed temporal separation. In the BESSY Medium Energy-FEL at a wavelength of 2 nm, residual bunching is mostly wiped out in the dispersive sections but can be partially conserved if the magnetic chicane setup is altered. Due to the relatively low power of these residual pulses compared to the nominal output power, it is not evident that these pulses are interesting to the user community. As an alternative, high intensity double pulses at the FEL exit can be achieved if the initial seed laser pulse is split up into two pulses which are delayed with respect to each other in an interferometer. In that case, the HGHG-FEL exhibits its full capacity of down-converting the initial double seed to a fraction of its wavelength with excellent spectral properties and high output intensities.

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