OUTPUT VARIABILITY OF THE BESSY* SOFT X-RAY FEL

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Abstract

The BESSY soft X-ray FEL is planned as a High Gain Harmonic Generation (HGHG) FEL multi-user facility covering the VUV to soft X-ray spectral range ($0.02\,keV \leq \hbar\omega \leq 1\,keV$). A photoinjector and a superconducting $2.3\,GeV$ CW linac will feed three independent HGHG-FEL lines. Depending on the optimization criteria, it is possible to obtain either maximum output power or a pure spectrum from the same HGHG-line. We present simulation studies for the BESSY-HGHG-FELs and discuss the possible variability of the output performance.

INTRODUCTION

Based on the experience with the third generation light-source, BESSY proposes a linac-based cascaded HGHG-FEL multi-user facility. The technical design report for the BESSY soft X-ray FEL was published recently [1]. The target photon energy ranges from $24\,eV$ to $1\,keV$ with a peak-brilliance of about $10^{31} photons\,/sec/mm^2/mrad^2/0.1\%\,BW$, i.e. a peak power of up to a few GW for pulse lengths less than $20\,fs$ (rms). The polarization of the output radiation will be variable.

Two to four HGHG stages are necessary to reduce existing laser wavelengths to the desired range of the BESSY FEL. Each stage consists of an undulator - dispersion - undulator structure. In the first undulator, the so-called modulator, the interaction with a radiation field (e.g. provided by an external laser) leads to an energy modulation of the electron beam on the seeding radiation frequency. The following dispersive section converts this energy modulation into a spatial modulation, or bunching, which includes bunching on higher harmonics of the seeding frequency. The second undulator, the so-called radiator, is set in resonance with a chosen harmonic of the seed. The prebunched beam then radiates at the harmonic wavelength and is instantly enhanced in radiation power [3]. The radiator output of each stage can be used as a seed for a next stage. The last radiator is followed by the so-called final amplifier. It is seeded at the desired wavelength and the amplification process is brought to saturation.

The BESSY HGHG multi-user FEL facility will consist of three undulator lines to cover the target photon energy range [1]. Each line is seeded by a tunable laser covering the spectral range of $230\,nm$ to $460\,nm$. The pulses have a Gaussian profile, a peak power of $500\,MW$, and a pulse duration of about $15\,fs$ (rms).

Out of the several combinations of harmonics that can be used to provide the desired wavelength range in each particular HGHG-line, the one requiring the minimal number of stages was chosen. The accessible harmonic content in the bunching drops with rising harmonic number and photon energy, limiting the usable harmonics to the first five. The fifth harmonic is used in the early stages, where, due to the long wavelength, enough power, and thus bunching can be obtained with acceptably short radiator lengths. Later stages use the third harmonic. The harmonic combination can change with the desired output wavelength. Each stage can operate on third or fifth harmonic of the used seed by moving the gaps.

For the performance of the HGHG-lines, the adjustment of the bunching, by setting the dispersion strength, is of major importance. Depending on the optimization criteria, it is possible maximize the output power or the spectrum purity at the same HGHG-line. In this paper, we present simulation studies for the BESSY-HGHG-FELs and discuss the possible variability of the output performance.

For the present simulation studies the dispersion section is modeled by a symmetric four-dipole magnet-chicane. The variations of the dispersion strength are taken into account by changing the field strength of the dipoles.

SPECTRUM OF A POWER-OPTIMIZED HGHG-FEL

For a Gaussian-shaped seed, only a part of the interacting electrons experience the full power due to the seed shape and the slippage effect. The impressed energy modulation mirrors the Gaussian profile of the seed. The strength of the dispersion section can be adjusted for the peak energy modulation at the center of the seeded part or for a somewhat lower energy modulation including the flanks. The second case provides the maximum output of the following radiator, since more electrons are optimally bunched. In this case the electrons at the center, which experience the full power of the seed are somewhat overbunched.

Figure 1 shows the bunching after the first dispersive section for the four-stage HGHG-FEL [1], the electrons at the center are already overbunched. The overbunching causes a power dip in the radiation pulse provided by the first radiator, as shown in figure 2a. Figure 2b shows the corresponding radiation spectrum. The overbunched electrons perform synchrotron oscillations in the ponderomotive bucket. The resulting modulation of the emitted radiation frequency causes the side spikes (sidebands) [2]. The more electrons are overbunched the stronger is the growth of the sidebands. This effect is repeated in the following stages. In this way the number of sidebands in the spec-

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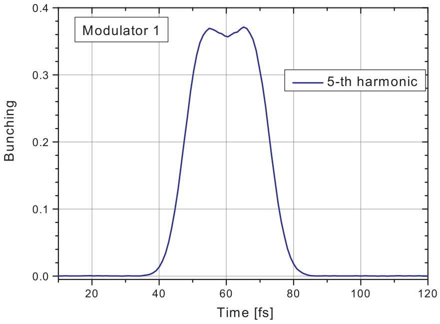

Figure 1: Bunching on the fifth harmonic after the first dispersion section for the four-stage HGHG.

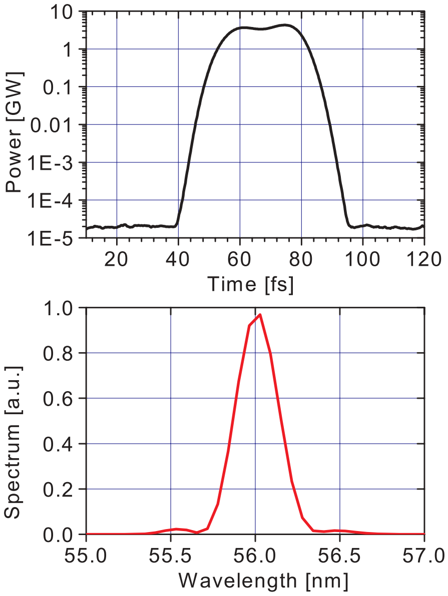

Figure 2: Simulation results for the first radiator of the four-stage HGHG-FEL a) the time resolved power distribution (top) and b) the spectral power distribution (bottom).

trum adds up from stage to stage. Due to the slippage in the radiators and final amplifier, the sidebands are shifted to one side.

Since in a cascaded HGHG-FEL, the output of each stage is used as a seed for the next stage, the raditor output has to be adjusted suitably. The bunching rate decreases with growing harmonics, therefore the dispersive section for a radiator resonant to the fifth harmonic has to be optimized such that more of the flanks of the Gaussian-shaped energy modulation are included to maximize the output power. This intensifies the overbunching in the middle of the seeded part and thus leads to stronger side spikes for the output on the fifth harmonic compared to the case of the output on the third harmonic. In general, the higher the harmonic numbers in the cascade the stronger are the sidebands for a power-optimized HGHG-line. For example, in the case of the three-stage HGHG-FEL the sidebands for $\lambda_s = 2.07\,nm$ with harmonic numbers $5 \times 5 \times 5$, figure 3b, are much stronger than for $\lambda_s = 12.4\,nm$ with harmonic numbers $3 \times 3 \times 3$, see figure 3a.

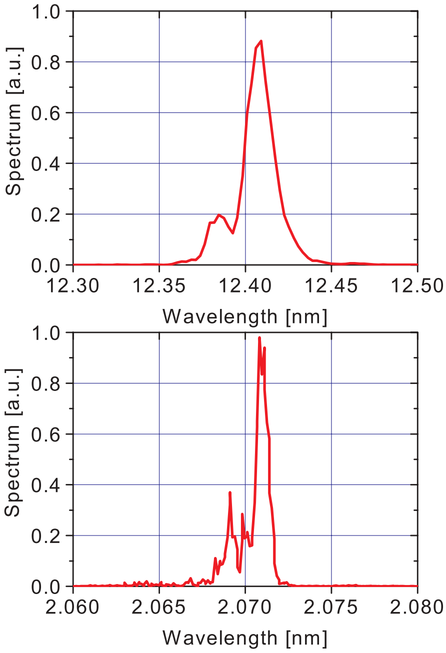

Figure 3: Spectral power distributions of the boundary wavelength of the three-stage HGHG-FEL, a) $\lambda_s = 12.4\,nm$ with harmonic numbers $3 \times 3 \times 3$ (top), b) $\lambda_s = 2.07\,nm$ with harmonic numbers $5 \times 5 \times 5$ (bottom) are shown.

SPECTRUM OF A PURITY-OPTIMIZED HGHG-FEL

The side spikes can be avoided by optimizing the dispersion sections for the peak energy modulation. In this case the bunching is of more Gaussian shape. The resulting radiation power and pulse length are reduced compared to the overbunched case, since less flank-electrons are optimally bunched. The losses in the integrated power are due to the reduction of the pulse length, i.e. the peak power suffers only slightly. This effect continues and adds up from stage to stage.

An example of the development of a spectrum purity-optimized case is shown in figures 4, 5, and 6 for the two-stage HGHG-line for $10\,nm$. The power and spectral distribution of the purity and power-optimized cases are displayed in the same graphs for comparison. For the purity-optimized case, the dipole fields of the dispersive chicanes are reduced by 12.5%. The reduction of the pulse duration and power in the purity-optimized case are evident.

The side spike of the purity-optimized case is less than

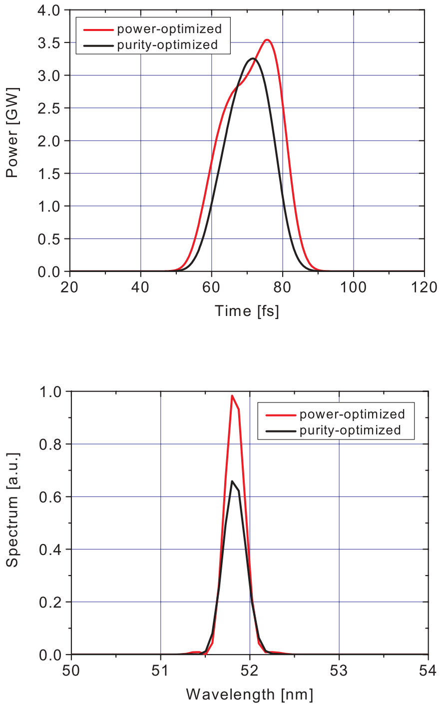

Figure 4: Power and spectral distribution of the first radiator of the two-stage HGHG-FEL.The purity-optimized and power optimized case are displayed in the same graphs for comparison. The reduction of the pulse duration and power in the purity-optimized case are evident.

half of the power-optimized case. Note that the peak power of the output does not suffer from the purity optimization.

CONCLUSION

The output performance of the BESSY soft X-ray FEL is variable not only in terms of polarization and wavelengths but also in terms of spectral properties. In a certain range, minor changes of the dipole strength in the dispersive section can be used to adjust the pulse duration, purity, and power of the output according to the experimental requirement. This emphasizes the quality of the BESSY-FEL as an user facility.

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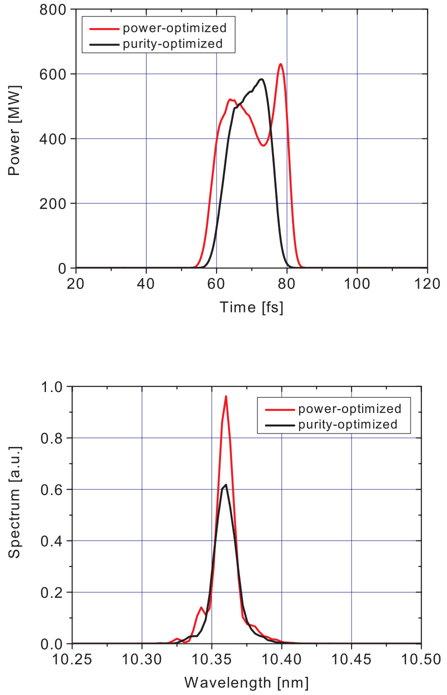

Figure 5: Power and spectral distribution of the second radiator of the two-stage HGHG-FEL.The purity-optimized and power optimized cases are displayed.

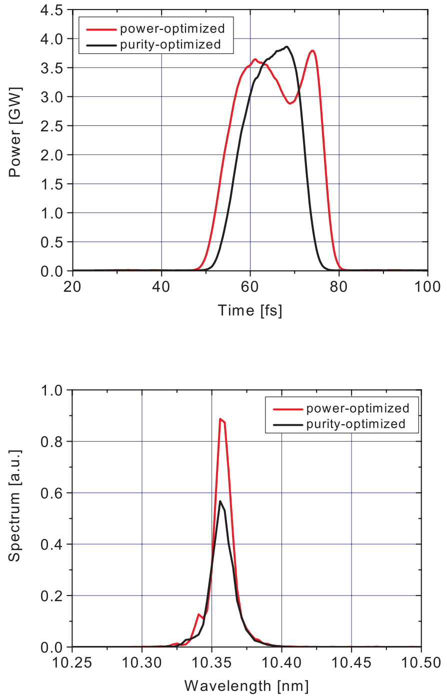

Figure 6: Power and spectral distribution of the final amplifier of the two-stage HGHG-FEL.Both, purity and power optimized cases are displayed.