THE POTENTIAL FOR EXTENDING THE SPECTRAL RANGE ACCESSIBLE TO THE EUROPEAN X-RAY FREE ELECTRON LASER IN THE DIRECTION OF LONGER WAVELENGTHS

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Abstract

The baseline specifications of European XFEL give a range of wavelengths between 0.1 nm and 2 nm. This wavelength range at fixed electron beam energy 17.5 GeV can be covered by operating the SASE FEL with three undulators which have different period and tunable gap. A study of the potential for the extending the spectral range accessible to the XFEL in the direction of longer wavelengths is presented. The extension of the wavelength range to 6 nm would be cover the water window in the VUV region, opening the facility to a new class of experiments. There are at least two possible sources of VUV radiation associated with the X-ray FEL; the ”low (2.5 GeV) energy electron beam dedicated” and the ” 17.5 GeV spent beam parasitic” (or ”after-burner”) source modes. The second alternative, ”after-burner undulator” is the one we regard as most favorable. It is possible to place an undulator as long as 80 meters after 2 nm undulator. Ultimately, VUV undulator would be able to deliver output power approaching 100 GW. A beam from this device could be run in pump-probe mode with X-ray FEL.

INTRODUCTION

Baseline design of present European XFEL project [1] assumed only standard (SASE FEL) mode for production of radiation. Recent developments in the field of FEL physics and technology form a reliable basis for perspective extensions of the XFEL facility. In [2] we proposed a concept of XFEL laboratory which will allow to implement perspective features from the very beginning of operation. These extra features include delivery of X-ray pulses in the attosecond regime, increasing of the FEL power (up to sub-TW level), simultaneous multi-undulator capability. The further development discussed in this paper concerns the expanded photon energy range to VUV range. This study will consider two possibilities: the first is based on ”electron switchyard” technique (see Fig. 1). The electron beam (at energy of 2.5 GeV) is . The electron beam (at energy of 2.5 GeV) is extracted from the main linac and enters transport line, which guides it to the VUV undulator located near the experimental hall. The beam distribution system consists of two transport lines. The first beamline (2.5 GeV) directs one bunch train, coming to the ”water window” undulator. The second beamline (17.5 GeV) takes every other bunch train and delivers it to X-ray undulators.

Figure 2 illustrates the second (baseline energy) option. This alternative is the one we regard as most favorable. The second option holds the energy at the baseline value (17.5 GeV) and chooses the undulator period length to match the water window wavelengths. This alternative is the one we regard as most favorable. Tables and present optimized parameters of undulator and FEL performance applied to ”water window” wavelength range with the electron energy of 2.5 GeV, and for the case of the maximum available energy (17.5 GeV). If the electron energy is that of the upper limit of the range of the baseline design (17.5 GeV) the undulator period length increases, for the resonant wavelength of 6 nm, from 4 to 11 cm. The FEL peak power is a factor of 10 higher for baseline energy (17.5 GeV). The saturation length of ”water window” undulator at 17.5 GeV is 80 m, against the 30 m of the low energy undulator.

The second option is the simplest way to obtain VUV radiation from the European XFEL. This is XFEL parasitic mode. All electron bunch trains will be guided into one electron beamline and dump. The wavelength range 0.1-6 nm at fixed electron beam energy of 17.5 GeV can be covered by operating the SASE FEL with four undulators which have different period and tunable gap. These SASE undulators can be placed behind each other assuming that the subsequent undulator radiates at longer wavelength. It is a great advantage that accelerator and electron beam transport line in this scheme operate at fixed parameters and that a fast ”electron switchyard” is not required. In order to avoid the need for a costly additional tunnels and shafts, the XFEL source is designed such that accelerator, all four SASE undulators, electron beam line, and photon transport beamlines are installed inside the same (5 m diameter) tunnel.

OPERATION OF FEL SOURCE AT LONGER WAVELENGTH

Present concept of an XFEL facility assumes to cover continuously wavelength range from 0.1 to 6 nm at a fixed (17.5 GeV) energy of the electron beam. This is achieved with four undulators installed in a series in one electron beamline. Optimization of undulator parameters has been performed for the electron beam parameters presented in [1]: peak current 5 kA, rms normalized emittance 1.4 mm-mrad, and initial energy spread of 1 MeV. All undulators are planar, variable-gap devices with an identical mechani-

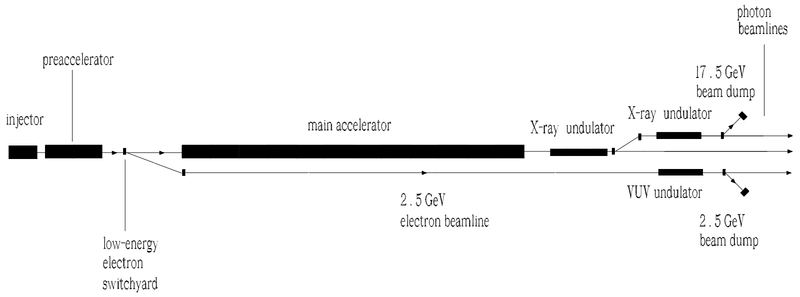

Figure 1: Schematic layout of the first possible strategy for VUV radiation. This scheme is based on the "electron switchyard" technique

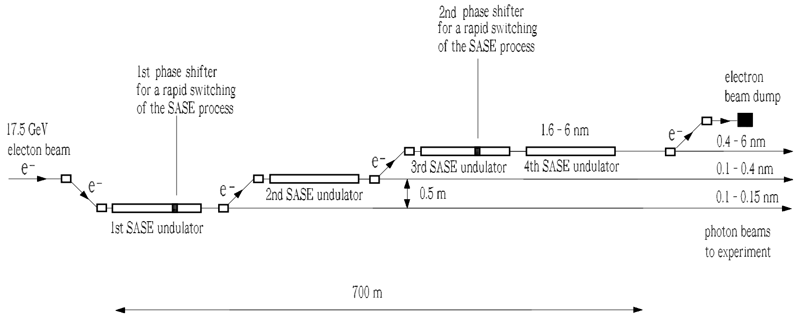

Figure 2: Schematic layout of the most favorable strategy for VUV radiation. In this scheme it will be possible to provide simultaneously hard X-ray and VUV radiation beams ("after-burner" mode of operation)

Table 1: Specification of soft X-ray undulators for XFEL laboratory

	Energy GeV	λ_u mm	gap mm	B_u T	L_u m
Nominal option	17.5	110	19-37	0.7-1.6	80
Low energy option	2.5	38	10-20	0.4-1	35

Table 2: Specification of soft X-ray FELs for XFEL laboratory

	Units	Nominal*	Low energy**
Energy	GeV	17.5	2.5
Wavelength range	nm	1.6/6.4	1.6/6.4
Peak power	GW	100/100	10/20
Average power	W	400/400	40/80
Photon beam size (FWHM)	μm	60/90	90/90
Photon beam divergence (FWHM)	μrad	11/27	11/30
Saturation length	m	70/80	18/32

*Operation in after-burner regime with rms energy spread of 8 MeV
**Operation with nominal energy spread of 1 MeV

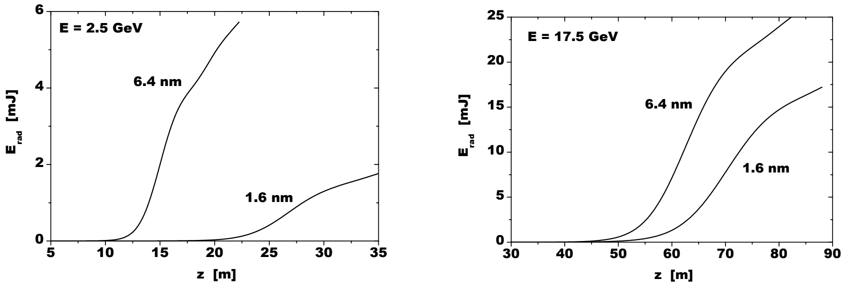

Figure 3: Energy in the radiation pulse versus undulator length. Left plot: low energy option (2.5 GeV). Right plot: nominal energy option (17.5 GeV).

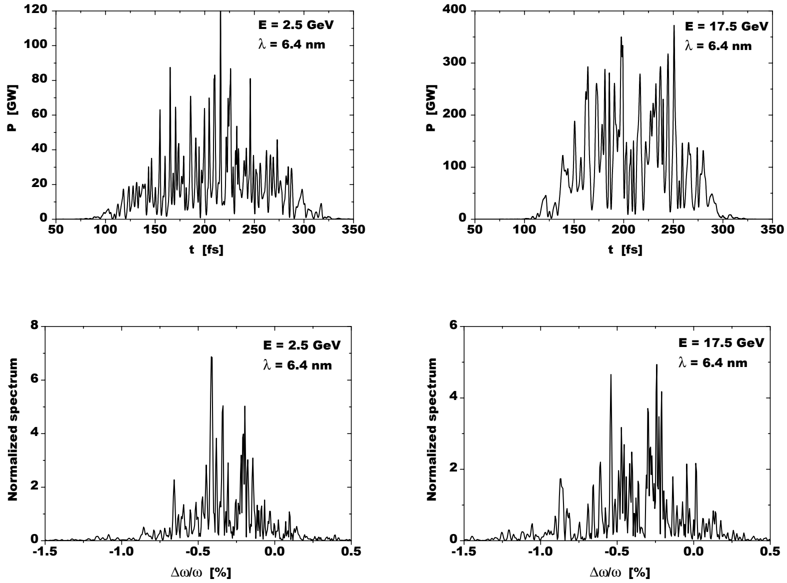

Figure 4: Temporal and spectral structure of the radiation pulse in saturation regime. Radiation wavelength is 6.4 nm. Left column: low energy option (2.5 GeV). Right column: nominal energy option (17.5 GeV).

cal design. Optimized parameters of the undulator for both cases are presented in Table . Calculations of the FEL characteristics are performed with time-dependent FEL simulation code FAST [3].

In this section, some examples will be given that shed light on the differences between the undulator applied to the VUV wavelengths with the electron energy of 2.5 GeV and an undulator that is modeled for the baseline energy 17.5 GeV (after-burner undulator). The build-up of the radiation pulse energy along the undulator is shown in Fig. 3. Requirements for FEL saturation at the shortest wavelength (1.6 nm) defines the undulator length: 35 m for dedicated 2.5 GeV option, and 80 m for 17.5 GeV after-burner option. Typical temporal and spectral structure of the radiation pulse from the VUV FEL operating at saturation are presented in Figs. 4 and 5. For both options these structures are very similar, while peak power is much larger for the after-burner option. At the wavelength around 1.6 nm all key parameters of SASE FEL (peak power, photon flux, brilliance) are by an order of magnitude higher for the after-burner option. This is an evident advantage for using high-energy electron beam to drive long-wavelength SASE FEL.

CONCLUSION

In this paper we performed direct comparison of two possible options to extend wavelength range of European XFEL towards 6 nm. The first option assumes to use electron beam extracted from the XFEL linac at the energy of 2.5 GeV. This beam is then transported via separate beam transport line, passes through the undulator, and is dumped

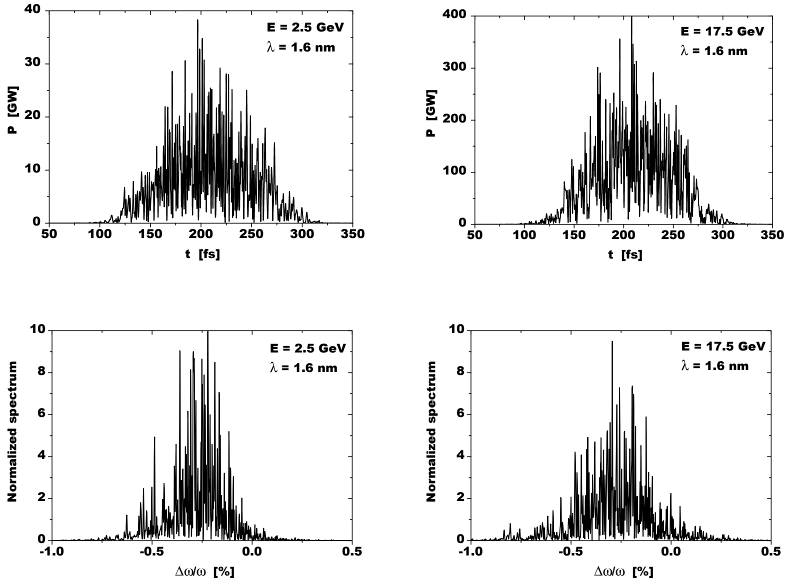

Figure 5: Temporal and spectral structure of the radiation pulse in saturation regime. Radiation wavelength is 1.6 nm. Left column: low energy option (2.5 GeV). Right column: nominal energy option (17.5 GeV).

into the beam dump. Extra expenses for this option are as follows. First, it requires to interfere XFEL linac in order to put extraction devices. Second, long beam transport line (of about two km long) is required. Third, it requires separate beam dump. These evident disadvantages can not be justified by relatively short undulator required (of about 35 meters). The second option, after-burner undulator is the one we regard as the most favorable. It uses electron beam with nominal energy of 17.5 GeV, and can be implemented in a parasitic mode of operation. It is possible to place an undulator as long as 80 meters after 2 nm undulator. Ultimately, VUV undulator would be able to deliver output power approaching 100 GW level (by an order of magnitude higher than for 2.5 GeV dedicated option). One should also keep in mind the problem of the overall efficiency of the XFEL laboratory, i.e. increasing the number of simultaneously working user stations. It is evident that 2.5 GeV option reduces the number of simultaneously working user stations: when electron beam is directed into the VUV branch, hard X-ray users need to wait. 17.5 GeV VUV option works in a parasitic mode: VUV pulse is produced by the electron bunch which was used for production of X-ray pulse in the previous undulator. Finally, in some modes of operation, VUV FEL radiation could be used with X-ray FEL radiation to do pump-probe experiments with precise intervals between the sources.

REFERENCES

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