ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPL038

STUDIES OF DISTRIBUTED OPTICAL KLYSTRON AT European XFEL

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Abstract

European XFEL is a x-ray free-electron laser (FEL) user facility covering a nominal photon energy range from 250 eV to 25 keV. At the soft x-ray undulator beamline SASE3 and the two hard x-ray undulator beamlines SASE1 and SASE2, identical permanent magnet phase shifters are installed. In standard operation of the hard x-ray undulator beamlines these phase shifters introduce only small delays between electron and photon beam. When operated with significantly higher delays, these devices can be used as dispersive sections in a so-called distributed optical klystron, resulting in faster generation of microbunching. In this contribution we give an overview of experimental studies of distributed optical klystron.

INTRODUCTION: THE DISTRIBUTED OPTICAL KLYSTRON

In high-gain free-electron lasers the exponential amplification process generates energy and density modulations at the scale of the radiation wavelength (so-called microbunches) as the electron bunch travels along the undulator beamline [1, 2]. Using the optical klystron (OK) effect [3–5], intra-undulator sections with longitudinal dispersion can be used to shear the energy-modulated longitudinal phase space distribution, which can result in a faster generation of microbunching. Being sensitive to the uncorrelated slice energy spread in the incoming electron beam, the OK process can also be used to measure the slice energy spread [5, 6].

This OK process can be repeated multiple times, resulting in a so-called distributed optical klystron (DOK) [7]. Measurements in this configuration were performed at the SwissFEL soft x-ray beamline “Athos”, which has magnetic chicanes between every second 2-meter-long undulator module [8]. At the radiation wavelengths of 2 nm and 1 nm the undulator length required for saturation was reduced by 30 % and 15 %, respectively [8], compared to standard FEL operation.

In this contribution we report on our first studies of DOK at European XFEL at a photon energy of 20 keV. This is the first time that DOK was studied at such high photon energies.

MEASUREMENTS AT European XFEL

At European XFEL [9], identical permanent magnet phase shifters [10] are installed in the intersections of all three undulator beamlines. As the maximum delay (and correspondingly the R_{56}) these devices can generate is defined by the requirements of the soft x-ray undulator beamline SASE3 [10], in the hard x-ray wavelength range therefore a significant delay on the order of tens of radiation wavelengths can be introduced. At the hard x-ray undulator beamlines SASE1 and SASE2 the phase shifters are installed after every 5-meter-long variable-gap undulator module and can be used as dispersive section for DOK-enhanced operation.

The preparation of a beamline configuration with distributed optical klystron is based on a setup with FEL lasing and the phase shifter strengths still in the standard range. The delay generated by the phase shifters is then increased to the desired range (by further closing the gap of these permanent-magnetic devices). The precise setpoints for best FEL gain then are determined by carrying out scans with the phase shifter software tool available for operation of European XFEL. Note that the phase shifter strengths are only increased in groups of a few devices at the same time, starting at the entrance of the undulator beamline. This group-wise procedure is required because if too many phase shifters were simultaneously converted from standard strength to the desired strength for DOK, the photon pulse energy measured with the installed diagnostics [11] would drop significantly and one would loose the input signal for the phase shifter scans.

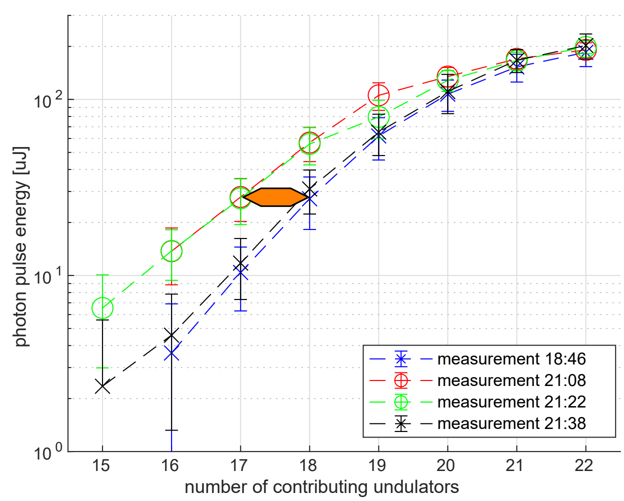

Figure 1: FEL gain curve measurements with DOK (round markers) and without DOK (cross markers) at SASE1 undulator beamline at a photon energy of 20 keV. In the DOK configuration, the same photon pulse energy is generated about 1 undulator cell earlier (orange arrow). The gain curves were obtained by opening the undulator modules one-by-one, starting at the end of the beamline.

After preparing the undulator beamline configurations (with DOK and with standard settings, respectively), FEL gain curves were measured by opening the undulators one-by-one (starting at the end of the beamline). We performed measurements at various photon energies at both hard x-ray beamlines SASE1 and SASE2. In Fig. 1, a set of gain curves

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ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPL038

measured at SASE1 beamline at a photon energy of 20 keV is shown (photon pulse energies corrected for spontaneous radiation background)[1]. Comparing the FEL gain curves taken with DOK on (gap of the phase shifters almost fully closed, total delay per 1.1-meter-long intersection 67 light wavelengths) with the data taken with the phase shifters set to a strength in the standard range (here: total delay per intersection 11 light wavelengths) we find that with DOK in the central range the same photon pulse energy is generated already about one undulator module earlier (orange arrow in Fig. 1). The increase of photon pulse energy generated with the same number of undulator modules (see for instance the data taken for 18 contributing undulator modules in Fig. 1) can be used for advanced FEL schemes such as hard x-ray self seeding (HXRSS) [12, 13], which at SASE2 beamline of European XFEL can use a maximum of 16 undulator modules to generate the photon pulses incident onto the second monochromatizing diamond crystal (in the case of single-monochromator operation). As the energy of the pulses incident on the crystal is one parameter influencing the performance of HXRSS, applying the DOK technique may help to extend the wavelength limits of HXRSS.

SUMMARY

The distributed optical klystron is a method to enhance the FEL amplification process. We performed measurements of this effect at the European XFEL hard x-ray FEL beamlines SASE1 and SASE2. In the measurement at SASE1 at 20 keV photon energy shown in Fig. 1, we save about one undulator module while generating photon pulses of same energy.

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