

ECHO-ENABLED HARMONIC GENERATION AT DELTA

R. Molo*,

M. Bakr, M. Höner, H. Huck, S. Khan, A. Nowaczyk, A. Schick, P. Ungelenk, M. Zeinalzadeh,
Center for Synchrotron Radiation (DELTA), TU Dortmund University, 44221 Dortmund, Germany

Abstract

We present conceptual studies of the realization of the echo-enabled harmonic generation (EEHG) technique as an upgrade of the present coherent harmonic generation (CHG) project at the DELTA storage ring. EEHG allows to reach shorter wavelengths compared to the CHG scheme. In addition to the optical klystron used for CHG, a third undulator is needed for a second energy modulation of the electron bunch, followed by an additional strong dispersive section. Installing these insertion devices requires a new long straight section in the storage ring and a new lattice configuration.

INTRODUCTION

DELTA is a synchrotron light source with a nominal electron beam energy of 1.5 GeV and is operated by the TU Dortmund University. The storage ring shown in Fig. 1 has a circumference of 115.2 m and comprises two undulators (U55, U250) and a superconducting wiggler (SAW). In order to produce synchrotron radiation with short wavelengths and ultrashort pulse durations (~ 50 fs), the coherent harmonic generation (CHG) [1, 2, 3] project at DELTA is presently commissioned during machine studies as well as during user shifts [4]. The newly proposed echo-enabled harmonic generation (EEHG) scheme [5], which can be viewed as an upgrade of CHG, allows to obtain shorter wavelengths and will be discussed in this paper. EEHG was successfully tested for the first time at SLAC [6] and SINAP [7], and studies exist of how to apply it at other linacs as well as at storage rings [8].

THEORY

The CHG scheme consists of two undulators and a chicane as shown schematically in Fig. 2. The electrons in the first undulator (modulator) interact with a co-propagating laser pulse, which is about 1000 times shorter than the electron distribution, and receive a sinusoidal energy modulation with the periodicity of the laser wavelength. A subsequent magnetic chicane converts this energy modulation into a density modulation (known as microbunching). Since the microbunches emit coherently in the second undulator (radiator), they radiate more intense than the rest of the bunch at the laser wavelength and harmonics thereof. The desired wavelength is selected by tuning the magnetic field of the radiator.

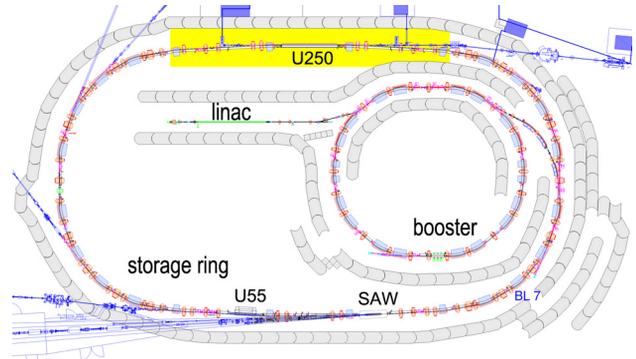


Figure 1: Schematic sketch of the DELTA synchrotron radiation facility. The yellow field denotes the vicinity of the northern straight section at which the CHG setup is located.

The radiated power from the microbunches at the n th harmonic of the laser wavelength is given by [9]

$$P_n(\lambda) \sim N^2 b_n^2(\lambda),$$

where N is the number of energy-modulated electrons, and $b_n(\lambda)$ is the so-called bunching factor that describes the degree of bunching between 0 (no microbunching) and 1 (perfect microbunching). In the case of CHG, the bunching factor [9]

$$b_n(\lambda) \sim e^{-n^2}$$

decreases exponentially with the square of the harmonic number n .

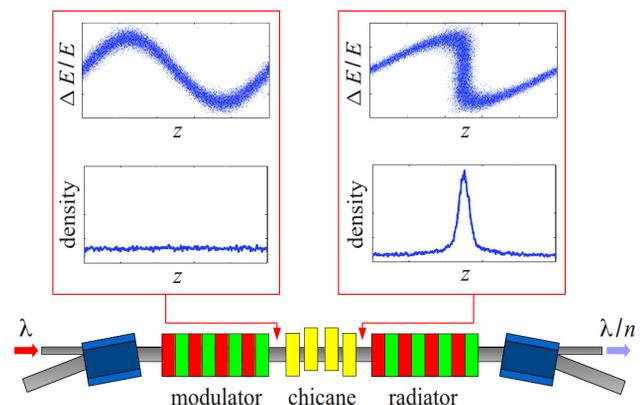


Figure 2: Schematic diagram of the CHG scheme with two undulators and one chicane. The longitudinal phase space diagrams show the electron distribution before and after the chicane.

* robert.molo@tu-dortmund.de

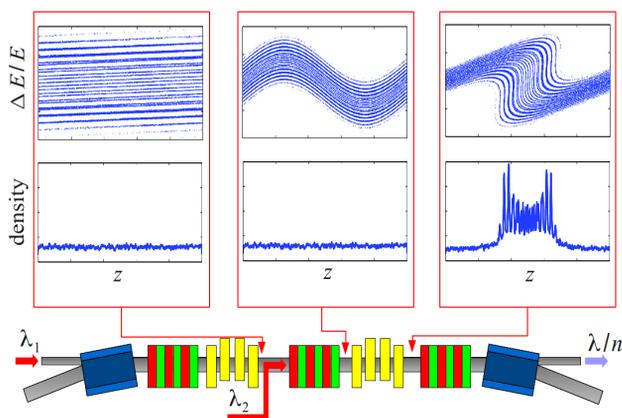


Figure 3: Sketch of the EEHG scheme with three undulators and two chicanes. The longitudinal phase space diagrams show the electron distribution after the first chicane, after the second undulator and after the second chicane.

In contrast to CHG, the optimized bunching factor for EEHG scales with the harmonic number as [10]

$$b_n(\lambda) \sim n^{-\frac{1}{3}}.$$

This allows to reach higher harmonics of the external laser and shorter wavelengths compared to CHG. The EEHG scheme (Fig. 3) requires three undulators and two chicanes. The interaction in the first undulator modulates the electron energy sinusoidally. Due to the large R_{56} in the first chicane, the electron distribution in phase space is so strongly tilted that almost horizontal energy bands are generated. The electrons interact again with a laser pulse in the second undulator. The second chicane with a moderate R_{56} produces a density modulation with a high harmonic content.

EEHG AT DELTA

Figure 5 shows the current CHG setup in the northern part of DELTA and the new solution for the EEHG configuration (for more details see [11]). In the present CHG setup, the straight section A is too short to install an additional undulator for EEHG. On the other hand, all components must be installed in a straight section in order to avoid dispersive distortions (transfer matrix elements R_{51} and R_{52}). Exchanging the 3- and 7-degree dipoles will increase the length of the straight section from 6.39 m to about 16 m, which is sufficient to install three undulators and two chicanes.

This new dipole magnet configuration requires a new quadrupole arrangement and should not affect the other parts of the storage ring outside the northern part of DELTA. Figure 5 shows a solution with only one additional quadrupole. Simulations for this new optics at DELTA were carried out using the code *elegant* [12], optimizing the quadrupole strengths and positions.

There are no sextupoles in the vicinity of the U250, and simulations show that the positions of the presently used

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sextupoles in the other parts of DELTA can be retained. In order to compensate chromaticity, however, their strengths have to be modified.

In section B, two new undulators M1 and M2, with a length of about 1.5 m, will be installed. Between them, the first chicane C1 with an R_{56} of the order of 1 mm will be placed. In section C, the undulator U250 will be used as radiator. A second chicane C2 with moderate R_{56} in the range of several $10 \mu\text{m}$ will be placed preceding the U250 undulator. A comparison between the present and the EEHG lattice properties is given in [11].

OPTIMIZATION

The EEHG scheme has six parameters to be optimized: the amplitude of energy modulation in the first and second undulator, the R_{56} of the first and second chicane, the relative phase ϕ between the two laser pulses as well as the ratio of the laser wavelengths λ_1/λ_2 . Due to the energy acceptance of the storage ring, which is limited by the accelerating RF to $\Delta E/E \approx 0.9\%$, an energy modulation of 0.3% has been chosen for both modulators. As a starting point, the relative phase was set to π and both wavelengths are 800 nm. As an example, Fig. 4 shows the bunching factor for the 24th harmonic of the initial wavelength depending on $R_{56}(1)$ and $R_{56}(2)$. There are three regions with a bunching factor higher than 0.1 (assumed as a safe limit for usable coherent radiation). A possible scenario is $R_{56}(1) \approx 1 \text{ mm}$ and $R_{56}(2) \approx 48 \mu\text{m}$.

Another approach is to find the highest harmonic n of the initial wavelength with a bunching factor higher than 0.1 for a given chicane configuration. Figure 6 shows that an $R_{56}(2)$ between 47 and $50 \mu\text{m}$ can be used to tune the coherent wavelength from the 18th to the 29th harmonic by changing the second chicane from 0.8 to 1.5 mm .

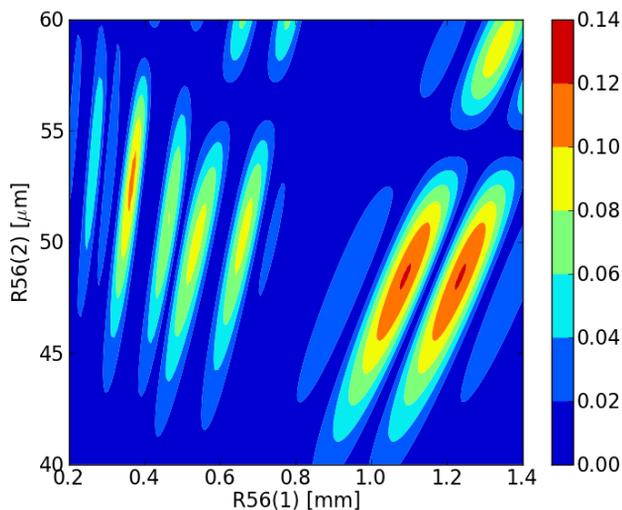


Figure 4: The bunching factor of the 24th harmonic of 800 nm for different chicane configurations.

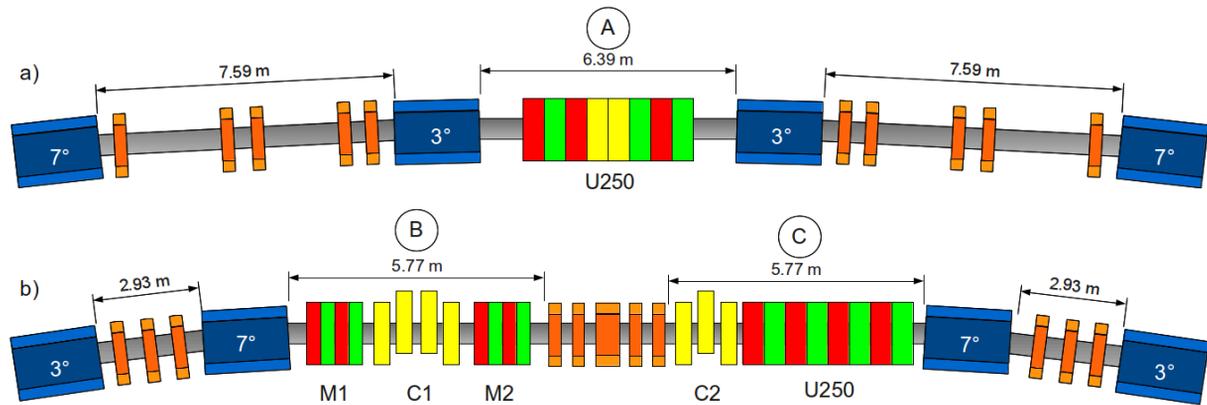


Figure 5: Schematic view of the northern straight section of DELTA. The orange, blue, and yellow blocks represent quadrupoles, dipoles, and chicane magnets ($C1$, $C2$), respectively. a) The present CHG setup: the undulator U250 is situated in section A between the 3-degree magnets. b) A possible EEHG setup: due to the exchange of the 3- and 7-degree dipoles, the straight section is largely extended and the present dipole chambers can be reused. The total storage ring circumference will be increased by about 3 cm, which is tolerable.

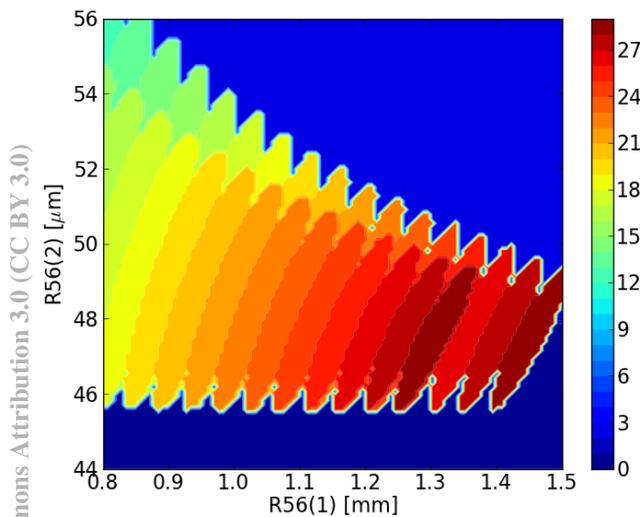


Figure 6: The highest harmonic n of 800 nm with a bunching factor higher than 0.1.

OUTLOOK

The new lattice configuration in the northern straight section of DELTA allows to establish the echo-enabled harmonic generation (EEHG) scheme and to produce, e.g., the 24th harmonic of an 800 nm femtosecond laser pulse with a bunching factor better than 0.1.

Since the EEHG scheme has two modulators, a new telescope design is needed to focus the laser pulses at two different positions. Another challenging aspect is to minimize field errors of the quadrupole and chicanes magnets as well as of the undulators in order to avoid dispersive distortions that would smear out the delicate phase-space pattern.

The radiator U250 in the new EEHG configuration can

be also used as modulator-chicane-radiator system as in the current CHG project. This provides the opportunity to test new seeding schemes such as the recently proposed triple modulator-chicane (TMC) scheme [13].

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