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FERMI CONFIGURATION FOR THE ECHO ENABLED HARMONIC GENERATION EXPERIMENT

E. Allaria*, D. Castronovo, M. Cautero, I. Cudin, B. Diviacco, M.B. Danailov, L. Giannessi, M. Veronese, M. Zangrando,
Elettra-Sincrotrone Trieste S.C.p.A., S.S. 14 km 163,5 in AREA Science Park, 34149 Trieste, Italy

Abstract

The FERMI FEL-2 undulator line, normally operated in the double stage high gain harmonic generation with the fresh bunch (HGHG-FB) has been temporarily modified to allow operating the FEL in the Echo Enabled Harmonic Generation (EEHG) scheme. An increase of the dispersion in the delay-line was required together with a replacement of the second stage modulator allowing the electron beam to resonantly interact with a second seed laser. Another critical component of the EEHG setup is a new manipulator installed in the delay-line chicane and hosting additional diagnostic components.

In this work we describe in some detail these new components that allowed a successful demonstration of the EEHG beam modulation at harmonics as high as 101.

INTRODUCTION

Echo Enabled Harmonic Generation [1] has been proposed as a viable method to extend seeded FEL operation with a single stage down to the soft-X-ray spectral range. Recent experiments have shown the capability of the EEHG scheme to sustain the coherent bunching up to harmonics as high as 75 [2]. However up to now, experiments have been limited to infrared seed laser and short radiator undulator. Hence the demonstration of the FEL amplification of EEHG bunching at short wavelength was not demonstrated yet.

In order to carefully characterize the EEHG mechanism in a condition capable of sustaining the FEL gain and optimized for short wavelengths, the FEL-2 line at FERMI [3] has been temporarily modified to allow EEHG seeding [4]. The upgrade required the installation of a new modulator for the second stage of FEL2, a new laser line delivering up to 50 µJ pulses at 260 nm. Figure 1 reports the layout of the FEL-2 undulator line for the standard operational mode (HGHG-FB) and for the EEHG.

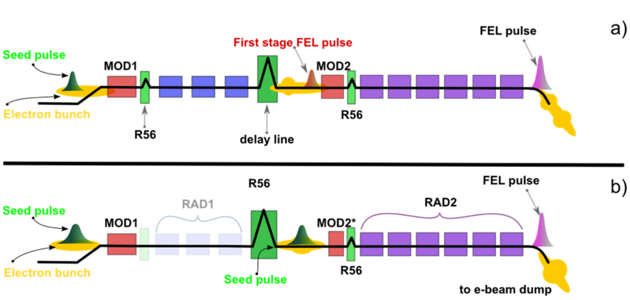

Figure 1: a) Nominal layout of FEL-2 for HGHG-FB. b) Modified layout used for the EEHG experiment.

*enrico.allaria@elettra.eu

Given the temporary scope of the modification, attention was given to allow a fast recovery of the standard operating mode of FEL-2 in HGHG-FB that could be restored within few weeks after the end of the EEHG experiment.

LAYOUT

The experiment has been setup in the FEL-2 line of the FERMI FEL. FEL2 is a two-stage cascade HGHG FEL usually operated in fresh bunch mode. Changes have involved the following systems.

New Modulator

In order to allow the resonant interaction of the electron beam with an UV seed laser, the second modulator had to be replaced by one with a longer period. An existing Elettra undulator was therefore modified to satisfy the EEHG requirements, and installed in April 2018. Its main parameters are reported in Table 1.

Table 1: New Second Stage Modulator Parameters

Parameter	Value	Units
Length	1.5	m
Period	113	mm
Maximum k	12	
Peak field	1.2	T

Large Dispersive Section

The possibility of EEHG to produce bunching at very high harmonics strongly relies on the use of a large dispersion (R56 of a few mm) in the first chicane. The required R56 necessary to produce bunching at harmonics higher than 40 has been obtained with a small upgrade of the existing chicane used for the delay-line in the HGHG-FB mode (Fig.1).

New Magnet Configuration The four magnets defining the delay-line chicane have been repositioned in order to increase the distance between magnet 1 and 2 (d1) and magnet 3 and 4 (d3). The distance between the central magnets 2 and 3 has been kept as small as possible, saving just the needed space to install the actuator for the laser injection (Fig. 2).

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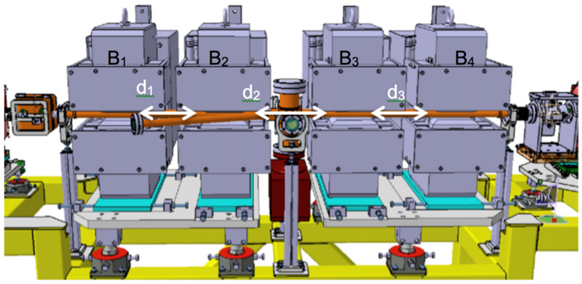

Figure 2: Drawing of the delay-line chicane.

New Power Supply In combination with a magnet reconfiguration we also changed the power supply in order to exceed the 500 A upper limit of the nominal FEL-2 configuration. For the purpose of the experiment a set of two power supplies providing 375 A each have been used in parallel. A master-slave configuration controlled with a feedback loop developed with LabView provided a stable and reliable current supply satisfying the EEHG requirements (Fig. 3).

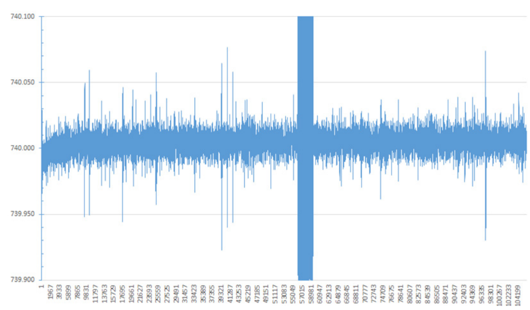

Figure 3: Stability of the power supply current at 750A with the configuration used for EEHG experiment.

New Seed Injection System

Injection of the second seed on the electron beam axis is realized with an in vacuum mirror placed on the electron beam axis in the center of the chicane. Since the electron beam off-set at the chicane center was of the order of 20-30 mm a careful design has been necessary to avoid interference between the manipulator and the electron beam.

The manipulator has been designed with a stiff construction while having small lateral footprint to comply with the limited space between the second and the third magnet of the delay line (Fig. 4). The in vacuum manipulator hosts several optical elements in addition to the laser injection mirror. Additional detail on the setup can be found in [5].

New Diagnostic

In addition to the injection mirror, the in-vacuum actuator hosts indeed a set of optical elements useful for the characterization of the laser and electron beam, when used in combination of a set of detector placed out of vacuum in the optical table close to the chicane.

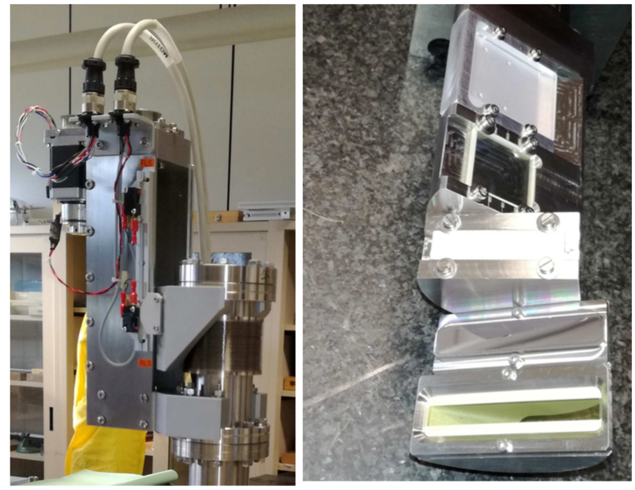

Figure 4: Left) Vacuum manipulator used for inserting on axis the seed laser mirror and the photon/electron diagnostic. Rigth) Vacuum components installed on the manipulator.

A YAG screen used in combination with a CCD is used for the characterization of the electron beam transverse mode and to monitor its position in the center of the chicane (Fig. 5-3). The same CCD can provide information of the laser spot on the mirror when used in combination with a UV scintillator (Fig. 5-2). A visible photodiode is used for measuring the arrival time of both the seed (diffusion from frosted Al) and the e-beam (OTR from Al foil) with an accuracy of 100 ps. A fast infrared detector can be used in combination with a set of IR filter for the characterization of the COTR signal produced by the beam when passing through an aluminium foil (Fig. 5-5).

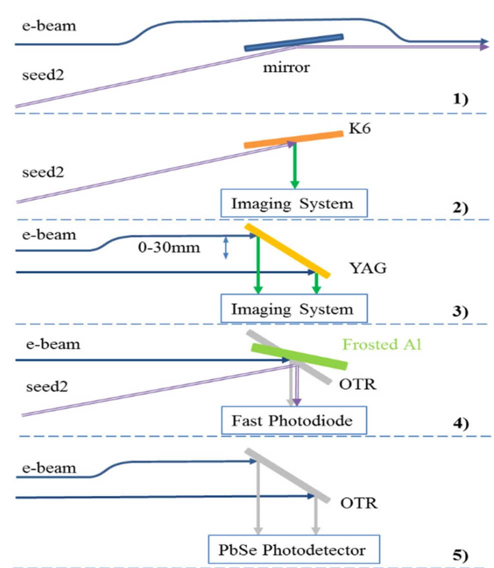

Figure 5: Diagnostic configuration.

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In order to extend the capability of the FEL photon diagnostic system [6] and being able to measure the spectral properties also for the week signal produced by the beam bunched at very high harmonics (~100) we have installed in the PADReS spectrometer an in vacuum CCD.

New Seed Laser

While the first laser needed for EEHG was obtained from the standard seed laser of FEL-2, for the second seed laser a new system was required. For the purposes of the experiment the second seed has been obtained by using the IR Ti:Sapphire laser pulses transported along the FERMI undulator hall to the user end stations.

These laser pulses, obtained from a second amplifier who is using the same oscillator as the first seed laser, are synchronized with a jitter lower than 6 fs rms with respect to the main seed [7,8].

Conversion from the IR to the UV, necessary for the EEHG seed, is done in the optical table placed near the magnetic chicane where all necessary instrumentation for an optimal control of the seed laser quality is available.

Main parameters for the second seed laser are reported in Table 2.

Table 2: Second Laser Parameters

Parameter	**Value**	**Units**
Wavelength	264	nm
Energy per pulse	<50	μJ
Pulse length	110	fs

RESULTS

Starting in May 2018, the new setup has been used for investigating EEHG at wavelengths ranging from 20 nm to 5 nm. The experiment allowed the successful demonstration of coherent and intense FEL pulses down to 5 nm [8].

The new diagnostic installed in the magnetic chicane has been capable of characterize both the electron beam (Fig. 6) and the seed laser allowing a perfect alignment of the two in the second modulator.

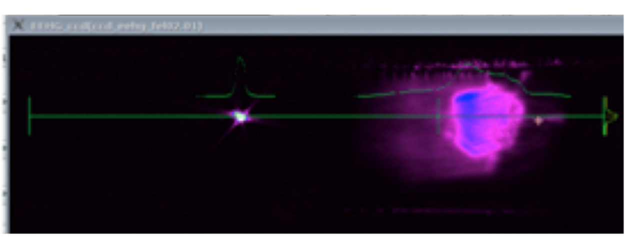

Figure 6: e-beam position (bright spot) measured with the YAG screen. Signal detected on the right side comes from CSR signal produced by the beam when passing the magnets.

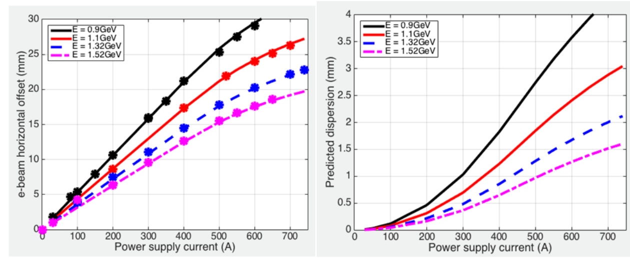

Figure 7: Left) Electron beam offset measurements compared to theoretically predictions. Right) prediction for induced dispersion.

The response of the magnetic chicane has been characterized by measuring the induced electron beam offset as a function of the power supply current and for different electron beam energies (Fig. 7). This allowed confirming the predicted values of R56 that are a critical parameter for the EEHG optimization.

The use of the new installed CCD in PRESTO has been necessary to detect the coherent signal generated by the EEHG at very high harmonics (H = 101) where the small undulator k could not support the FEL amplification (Fig. 8).

CONCLUSIONS

An EEHG setup has been implemented at FERMI on the FEL-2 line allowing studying EEHG in the soft x-ray spectral range.

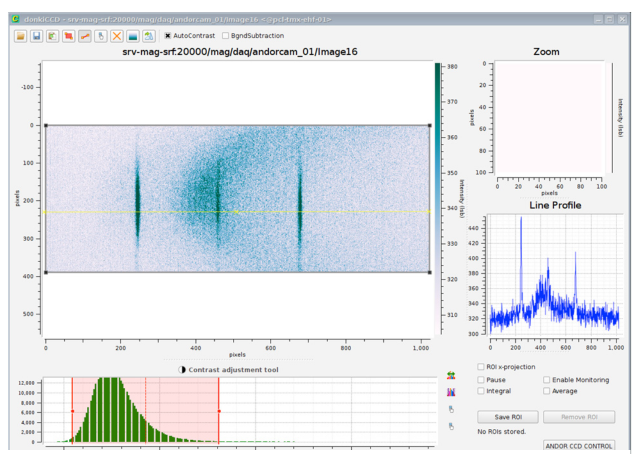

Figure 8: Central peak refer to the second diffraction order of the radiation at harmonic 101. Lateral peaks refer to first diffraction order of the radiation emitted at harmonics 50 and 51.

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