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THE NEW DIAGNOSTIC SUITE FOR THE ECHO ENABLED HARMONIC GENERATION EXPERIMENT AT FERMI.

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Abstract

The Echo Enabled Harmonic Generation (EEHG) experiment has been implemented on the FEL2 line of the FERMI FEL at Elettra (Italy). The main purpose is to validate the expected performance improvements at short wavelengths before a dedicated major upgrade is deployed. This paper describes the new diagnostics and the operational experience with them during the EEHG experiment. By means of a multi position vacuum vertical manipulator, different optical components are positioned on the electron and seed laser path. Both transverse and longitudinal measurements are performed. A YAG:Ce screen (e beam) and a terbium doped UV scintillator (laser) are imaged on a dedicated CMOS camera. For the temporal alignment, an OTR screen and a scattering surface are used to steer radiation from the e-beam and laser, onto a fast photodetector. Also coherent OTR radiation, due to micro-bunching, is acquired by means of a PbSe photodetector. Finally, for the normal EEHG operation, the laser beam is injected on the electron beam axis by means of a UV reflecting mirror. The results of the installed diagnostics commissioning are here presented.

INTRODUCTION

One the most recent advances in Free Electron laser design is the so called Echo Enabled Harmonic Generation [1]. In this scheme the electron beam is modulated by two external lasers, compared to High Gain Harmonic Generation (HGHG) [2] where one seed laser is used and to Self Amplified Spontaneous Emission (SASE) [3] which has no external seeding and is based on amplification of shot noise microbunching, Recently microbunching at the 75th harmonic has been observed using a seed laser at 2400 nm [4]. In HGHG the external seed laser couples to electron beam in the modulator undulator to produce a bunched current distribution, then the electron beam pass through the radiator undulators and lasing occurs. The HGHG emission has a quicker built up compared to SASE. HGHG pulses have a high spectral purity and stability and can be fully coherent and transform limited [5] . The main limitation of HGHG at short wavelengths is its sensitivity to quality of the electron beam in terms of phase distortions [6]. EEHG can potentially decrease the sensitivity of the FEL to the electron beam quality and thus ease the operation of the FEL at short wavelengths. Moreover since in EEHG there is no FEL first stage, the beam does not undergo properties degradation due to first stage and so there is no need to use the fresh bunch technique [7] typical of HGHG multiple cascade FELs. This means that potentially the compression can be increased allowing for higher peak current. An EEHG experiment has been proposed [8] and installed in the FERMI FEL2, to validate the expected improvements. The experiment is aiming at comparing FEL operations in EEHG mode and in standard two stage HGHG with an electron beam energy ranging from 1.1 GeV to 1.5 GeV for wavelength in the 20 to 4 nm spectral range. Finally a new manipulator and diagnostics have been installed in the delay line and are the subject of this paper.

EEHG LAYOUT

The experiment has been setup in the FEL2 line of the FERMI FEL. FEL2 is a two stage cascade HGHG FEL usually operated in fresh bunch mode. The upgrade for the experiment involves the installation of a new modulator for the second stage of FEL2, a new laser line delivering up to 50 microJoules pulses at 260 nm with duration around 150 fs. The magnetic delay line magnet will be repositioned and a new power supply capable of 750 Amp has been installed allowing to reach R56 above 2 mm. The EEHG modulator undulator has variable gap, linear polarization and a period of 11 cm to fit the laser wavelength of 260nm. Figure 1 shows

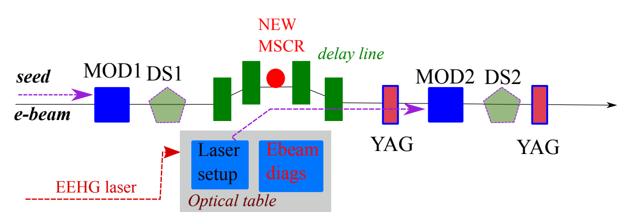

Figure 1: Layout of EEHG experiment at FERMI.

a pictorial layout of the EEHG experiment. The seed laser of the first stage is called ‘seed1’ and the first stage radiators are not depicted since they are not needed for EEHG and have been set at gaps fully open during the measurements. MOD1 is the first stage modulator and DS1 is the first dispersive section. The magnetic delay line is depicted as a series and green rectangles and is used as the main big R56 needed for EEHG. In the middle of it the new vacuum manipulator has been installed. On the lower part a gray rectangle depicts the optical table that houses all the laser setup that controls the steering, the compression and the third harmonic conversion to generate the ‘seed2’ UV laser. On the same table we also installed all the motorized actuators and detectors that compose the new diagnostics. Downstream this area we can see in Fig. 1 the YAG:Ce screens are depicted as red rectangles.

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They are used for the transverse alignment of the seed laser vs the electron beam. The new modulator MOD2 is a blue rectangle and DS2 pentagon depicts the second dispersive section. Downstream of it the standard FEL2 radiators are converting current modulation in FEL pulses.

DIAGNOSTICS CONFIGURATIONS

The new diagnostic suite has been requested to provide several configurations that are depicted in Fig. 2 in a simplified form. The first request is to house the UV mirror needed for injection of seed2. The second is to be able to provide imaging of the seed2 laser on the same plane of the mirror for alignment and reference purposes. The third is to provide electron beam imaging for all the 30 mm range of transverse displacement possible by change the delay line current from 0 to 750 Amp. The fourth is to provide coarse longitudinal alignment of seed2 vs the electron beam. The final request was to provide microbunching measurements by CTR power measurements in the infrared.

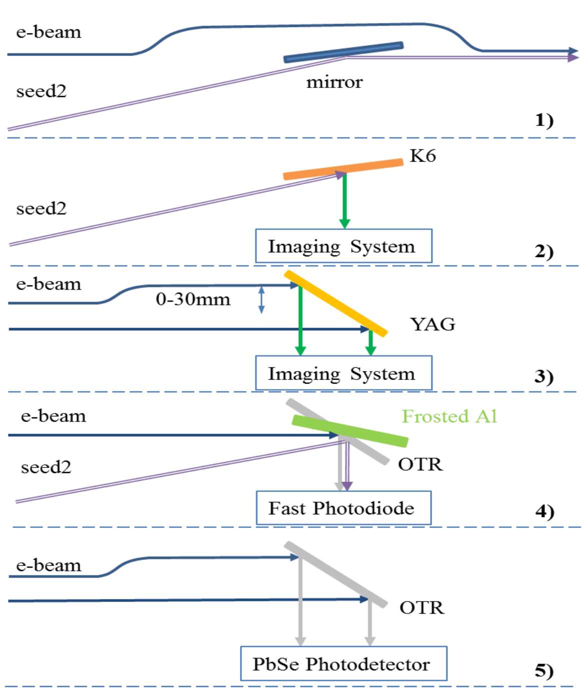

Figure 2: Diagnostics configurations.

DIAGNOSTICS LAYOUT

This diagnostics upgrade involves a new vacuum chamber for the delay line for the injection of the seed2 lase at 20 deg, the installation of a new motorized manipulator and optimal geometry for the extraction of diagnostics related radiations. The manipulator is located at the center of the FEL2 magnetic delay line. The manipulator is required to have high stability and angular reproducibility. It is equipped with a UV high reflectivity dielectric mirror, a scintillator to image the seed2 laser, a frosted aluminum plate for coarse temporal alignment and an OTR screen for the same purpose as well as for the purpose of microbunching measurements and finally a YAG:Ce scintillator for electron beam transverse profile measurements.

MANIPULATOR AND VACUUM COMPONENTS

The manipulator chamber is equipped with a commercial Pfeiffer vacuum manipulator with 150 mm travel.This manipulator has been chosen for the stiff construction while having small lateral footprint to comply with the limited space between the second and the third magnet of the delay line. The manipulator has been customized equipping it with a Renishaw digital encoders (Tonic) with 0.1 micron resolution. The second customization also includes precision holes for dowel pins in the vacuum chamber and in the manipulator to provide a highly reproducible installation in case of need for mirror replacement. The manipulator is shown in Fig. 3. The different angle and the targets size involved lead to a complex design of rod leaving so little material in some parts that we were force to used stainless steel to provide the required robustness. The angular reproducibility of the steering angle over a full travel repositioning of the manipulator has been measured to be of 70 nrad by imaging the seed2 laser on the downstream IUFEL YAG screens. The lateral displacement of the full travel is of about 5 microns. The vertical position accuracy is less then 1 micron in closed loop. The extraction window is orthogonal to the electron beam propagation direction for diagnostics. As consequence of the multiple requirements it has been chosen of CF63 size and CaF2 has been used to provide transmission up to a wavelength of 10 microns. Figure 4 shows a picture of the

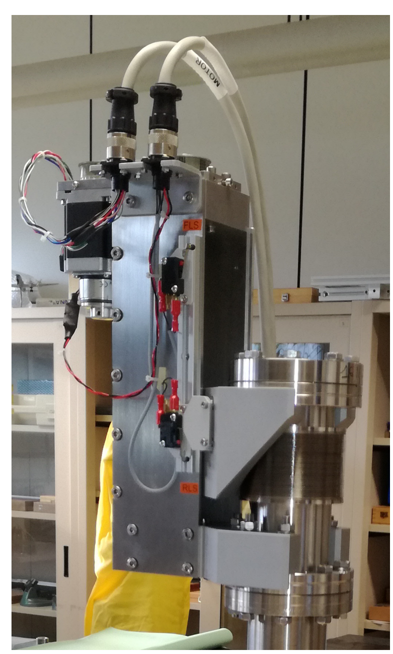

Figure 3: Vacuum manipulator.

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manipulator rod oriented orthogonally to the electron beam. The uppermost component is the UV high reflectivity dielectric mirror axis. Moving downwards we find the Metrolux K6 scintillator for seed2 imaging, the the frosted aluminum plate used to scatter the seed2 making easier the alignment and less dangerous for the photodiode the high energy laser. Then we find the 1 micron aluminum tensioned foil from Luxel that acts as OTR screen. Finally at the bottom of the rod we installed the YAG:Ce scintillator with a chromium precision recticle deposited on it for calibration purposes.

Figure 4: Vacuum components installed on the manipulator.

OPTICA TABLE SETUP

Since all radiations leave the vacuum from the same viewport but have different source points and multiple measurements are requested we have devised the setup shown in Fig. 5. At 100 mm from the window we installed a XY motorized translation stage with 100 mm horizontal travel and and 50 mm vertical travel. It is equipped with a fast photodiode for temporal coarse alignment and a IR slow photo detector for microbunching measurements. The fast photo detector is Hamamatsu G4176 connected to a 6 GHz Tektronics digital oscilloscope via a bias tee and AIRCOM PLUS low attenuation coaxial cables. The arrival time of the electron beam is marked by the position of the photo detector signal generated by optical transition radiation emitted by the OTR. The seed2 temporal arrival time is obtained by the signal detected on the photo detector after the laser scattered from the frosted aluminum target installed on the manipulator rod. About 50 mm horizontal travel of the XY stage are left available as free path without obstacles to allow imaging of the Metrolux and Crytur scintillators. Imaging of both scintillators is achieved with a single device installed on a 50 mm motorized translations stage. Electron beam imaging can be performed both on OTR and YAG:Ce target. The targets are of 56 mm wide to allow for a filed of view of 30 mm needed to be able to make measurements in the

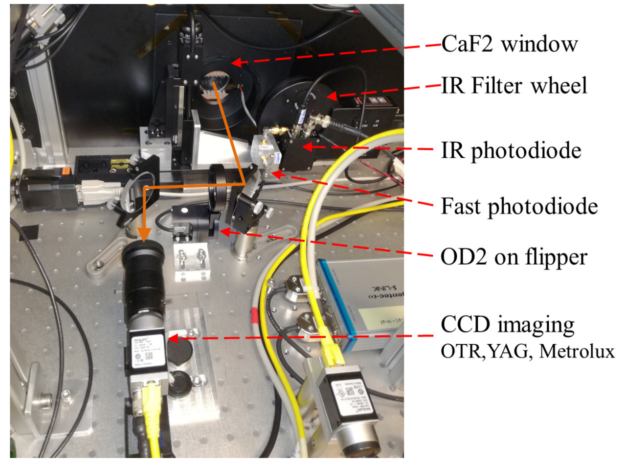

Figure 5: Layout of optical components and detectors.

full range of the delay line. The imaging systems consists of a 75mm focal length lens coupled to a 1/2 inch Basler acA1300-75gm CMOS camera. The working distance providing the 30mm horizontal filed of view is of 550 mm. The iris is set to f11 to maximize the depth of field without compromising the resolution. But even in such a configuration the depth of field it is not enough to have the full FOV in focus so the camera is installed on a 50 mm translation stage that is used to change the focus when the electron beam hits a lateral part of the screens. To increase the contrast we have installed behind the YAG a white peek frame. Finally to compensate for the difference of intensity between OTR (as shown in Fig. 6), YAG and Metrolux scintillator an optical density 2 visible neutral density filter has been installed on a remotely controlled flipper on the optical path. Laser beam

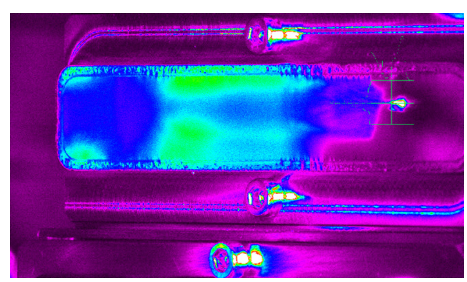

Figure 6: Electron beam imaging on OTR screen.

imaging is important to check the alignment and to guarantee the correct superposition of electron beam and seed2. In the EEHG setup it is done in three positions. The first is the Metrolux scintillator installed in vacuum on the manipulator rod. The second is 1.7 m downstream of the manipulator on the YAG:Ce scintillator of the closest IUFEL screen. The the last measurement point is at 6.2 m from the manipulator on the next IUFEL screen. Figure 7 shows the EEHG laser spot on the Metrolux scintillator as imaged by the optical system installed on the table. The same optical system also provides the imaging of the electron beam on the YAG:Ce screen.

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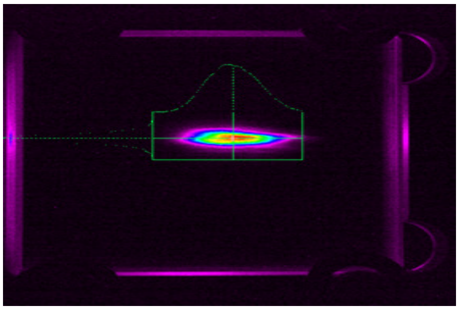

Figure 7: Seed2 laser spot imaging on Metrolux scintillator.

MICROBUNCHING

Microbuncing is crucial aspect influencing the final performances of the FEL especially for the FEL2 short wavelength FEL. For this reason we have equipped this diagnostic station with a system for measuring the coherent transition radiation (CTR) due to microbunching. To have more detailed information of microbunching as a function of other machine parameters such as the laser heater power, the compression, and the magnetic delay line current instead of having just a power measurement we have installed a device capable of providing spectral information. The device is installed on XY stage and consists of a filter wheel and an infrared detector. The filter wheel is equipped with infrared band pass filters with 0.5 microns bandwidth (Thorlabs 1inch FB series) and a central wavelength of 1.75, 2.25, 2.75, 3.25 and 3.75 microns. The detector is a PbSe photo detector (Thorlabs PDA20H) whose responsivity spans the wavelength range from 1.5 to 4.5 microns. The signal of the photo detector is acquired with a digital oscilloscope. Figure 8 show intensity data as a function of the filter wavelength for a value of the delay line of 300 A and different values of the Laser heater energy. The data are normalized to detector responsivity and then to the signal without filters scaled by an average of the responsivity. As could be expected increasing the laser heater energy causes a reduction of the intensity of CTR. The spectral selectivity of the device also allows to see that the intensity is higher a shorter wavelengths. Moreover as the laser energy is increased the heating seems to be of unequally efficient depending on the wavelength. Recoding curves as the one in Fig. 8 one can have reference data and identify relative variations on long term operation of the machine.

CONCLUSIONS

The instrumentation installed has performed reliably both in terms of EEHG laser injection system as well as laser and electron beam diagnostics. In particular the microbunching CTR has allowed to characterized the IR range spectral range and to provide a relative reference to be used for future comparisons as a simple and direct way to establish the presence and the magnitude of microbunching in the electron beam. We are currently considering ways to extend the spectral range of this diagnostics both to the longer and shorter wavelengths to provide a more complete understanding of the spectral distribution of microbunching.

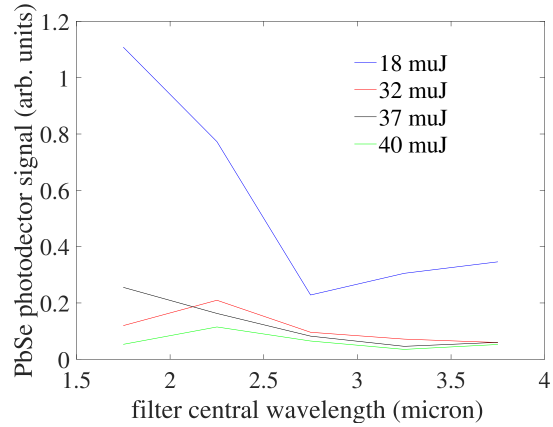

Figure 8: Spectral distribution of microbunching intensity as a function of laser heater energy.

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