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HIGH LEVEL SOFTWARE FOR OPERATING AN EEHG FEL

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Abstract

Reliable operation of a seeded Free Electron Laser (FEL) requires the simultaneous control of several electron-beam, laser and accelerator parameters. With Echo Enabled Harmonic Generation (EEHG) the complexity increases due to the second seed laser and the strong dependence of EEHG bunching to seeding parameters. With the recent upgrade of the FEL - 1 line, FERMI is the first FEL facility to be operated in EEHG mode for users. This required a major work for developing software tools that could be used to easily set the FEL at the desired wavelength. We report here on the recent software developments at FERMI for the operations of the new FEL - 1.

An important prerequisite for EEHG is to determine both the electron beam energy spread and seed laser induced energy modulation. This is done by using High Gain Harmonic Generation (HGHG) time dependent bunching equations to match experimental parameters scans. With these data, optimal EEHG settings of the machine parameters are then calculated to reach the desired FEL wavelength. The requested parameters are then sent to interface tools that accurately control laser, undulator, chicane and electron beam.

EEHG SETUP FOR FERMI FEL - 1

The FERMI FEL - 1 [1] beamline has been recently upgraded to allow EEHG [2] operations. Thanks to this upgrade the FEL - 1 performances have recently expanded with a significant extension of the tuning range toward short wavelength and an improved spectral quality [3].

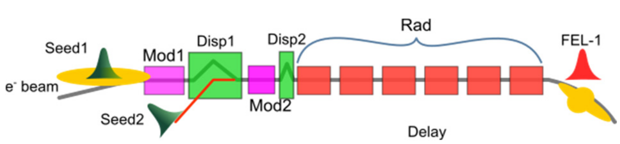

Figure 1: Layout of the upgraded FEL-1.

The new FEL - 1 (Fig. 1) is equipped with two independent lasers, two modulator undulators, two dispersive sections and 6 radiator undulators.

Seed Lasers

Two UV seed lasers are used for EEHG operations of FERMI FEL - 1. $Seed_1$ is at fixed wavelength, pulse length is normally of the order of 200 fs and can be adjusted acting on a dedicated grating compressor. Tuning of the FEL wavelength is done by setting the $seed_2$ laser wavelength that is can be adjusted in the range 245 – 265 nm. $Seed_2$ pulses are very close the Fourier limit with a pulse length well below 100 fs and compression is done with dedicated chirped mirrors. Each laser has dedicated motors and diagnostics for transverse and longitudinal alignment as well for intensity control.

Modulators

First modulator is a 3 meter long planar undulator with 10 cm undulator period. Second modulator is 1.5 meter long with 11.3 cm period. For both undulators the resonance condition from 200 nm up to more than 400 nm can be controlled with the variable gap.

Dispersive Sections

A newly designed chicane has been installed for the first dispersive section. EEHG indeed requires the dispersion of the first chicane to have an R_{56} of the order of few millimetres that could be achieved with the existing chicane. Moreover, the first chicane should also allocate the injection mirror for the second seed laser and some dedicated diagnostic for laser and electron beam characterization. The R_{56} of the first chicane can range from 1.0 to 10 mm when the second seed injection mirror is installed. The full range from 0 to 10 mm can be exploited if no element are placed on the electron beam axis. The second chicane is the standard HGHG chicane used for both FEL - 1 and FEL - 2 at FERMI with an R_{56} ranging in the range 0 – 200 μm.

Radiator

FEL amplification occurs in the radiator composed by 6 APPLE-II undulator. Each radiator undulator is 2.4 m long with 5.5 cm undulator period. Electron focusing magnets and diagnostic are placed at each intra undulator section in the radiator.

SEEDED OPERATIONS

A seeded FEL exploits the coherence imprinted by the seed laser to the electron beam to control the FEL amplification and improve temporal and spectral properties of the radiation.

A typical seeding process starts with the creation of an energy modulation imprinted by the seed laser on the electron beam in an undulator called modulator. The amplitude of the energy modulation ΔE is normally compared with the intrinsic electron beam slice energy spread σE using the adimensional parameter $A= \Delta E/ \sigma E$. The dispersion R_{56} is used to convert the energy modulation into density modulation (bunching) before the beam enters the radiator.

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HGHG OPERATIONS

With HGHG, in order to allow the generation of enough bunching at high harmonics a large energy modulation is required with an A typically of the order of the desired harmonic.

Once the optimal superposition between the electrons and the seed laser has been found, optimization of the bunching can be achieved with a scan of either the strength of the dispersive section (R_{56}) or the intensity of the seed laser (A).

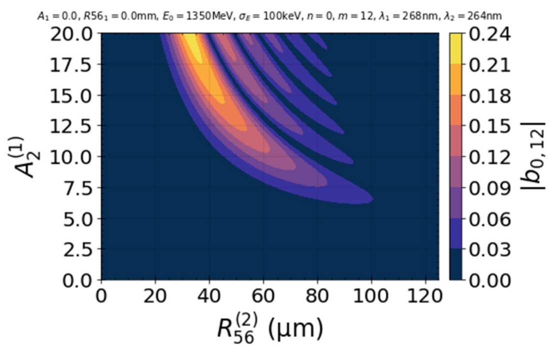

Figure 2: HGHG bunching as a function of dispersion and laser strength.

Provided that both the R_{56} and the seed laser intensity (A) are above a given threshold both scans can easily identify the best working point. Moreover, both parameters can be used for a fine tuning of the bunching at the desired harmonic entering the radiator and accurately control the output FEL power.

EEHG OPERATIONS

In EEHG the generation of the desired bunching at the harmonics comes from a combination of the energy modulations independently introduced by the two seed lasers and the dispersions occurring the two chicanes. Optimal setting of the four parameters (A_1, A_2, $R_{56}{}^1$, $R_{56}{}^2$) is then required for operating EEHG. Moreover, given that the final FEL wavelength is the result of a frequency mixing of the two seed laser frequency in general more solutions exist for the seed laser wavelength that provide the required FEL wavelength.

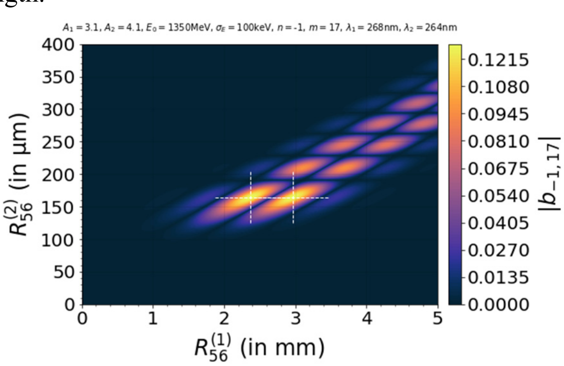

Figure 3: EEHG bunching as a function of the two dispersive section strength for given A1 and A2 (see caption).

Given the $seed_1$ and $seed_2$ laser wavelengths a precise setting of the two dispersive section is required for generating bunching at a given FEL wavelength as reported in Fig. 3. A linear relation between the dispersion of the two chicanes providing some harmonic bunching can be recognized. The optimal settings of the two chicanes (white crosses in Fig. 3) depends however on the exact values of the other EEHG parameters (A_1, A_2).

For a given setting of the two chicanes sensitivity to the strength of the two seed lasers (A_1, A_2) can be seen in Fig 4.

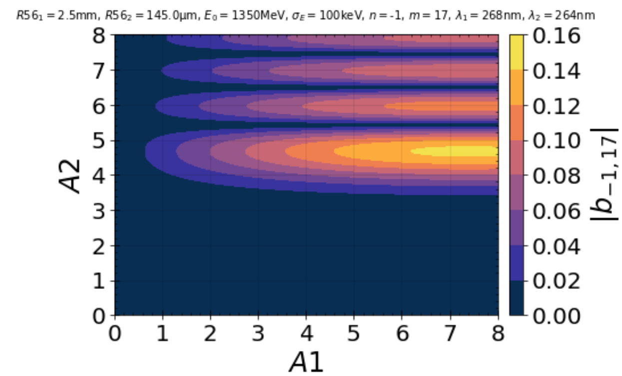

Figure 4: EEHG bunching as a function of the two seed laser intensity for a given setting of the two chicanes (see caption).

As a result of the interplay of the various parameters, the map of the bunching vs the second seed laser intensity (A_2) and the second dispersive section ($R_{56}{}^2$) (Fig. 5) is significantly different than the one for standard HGHG (Fig. 2)

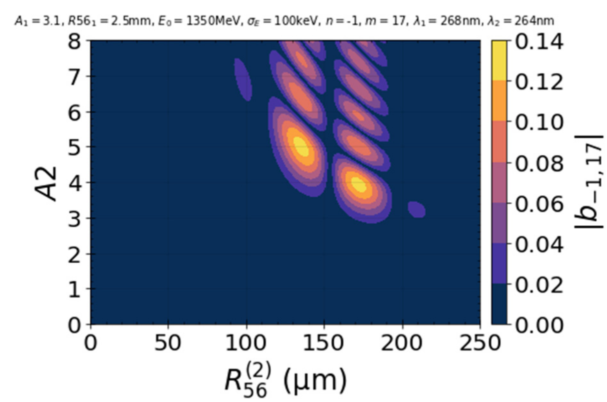

Figure 5: Map of the EEHG bunching as a function of the second seed laser intensity and dispersive section for a given setting of the first seed laser intensity and dispersive section.

Given this complex sensitivity of EEHG bunching to all the parameters, for an optimal operation of EEHG FEL as a user facility it is absolutely necessary been able to set the machine parameters based on a reliable model of the machine rather than performing scans at each wavelength change.

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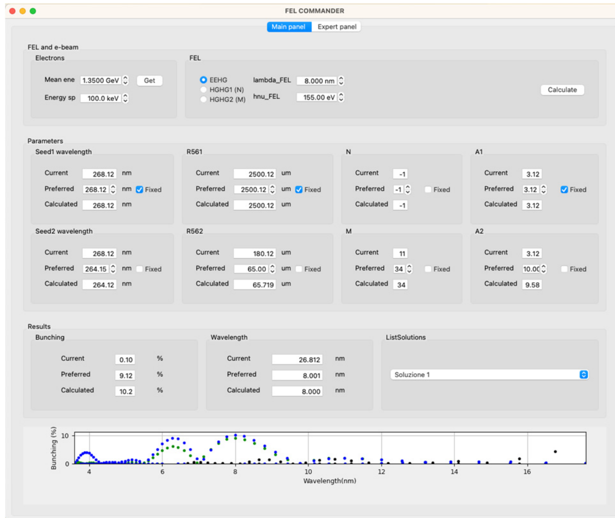

Figure 6: Panel used to operate FEL in EEHG configuration.

MACHINE PARAMETERS

The values of the R_{56} for the two chicanes is known with a good accuracy thanks to laboratory measurements and beam-based calibration, a high-level software has been provided that can set the chicane to the required R_{56}. Also, the wavelength of the two seed lasers is measured with high accuracy and provided to control system; moreover, the wavelength of the second seed laser can be controlled via software. What is not directly available to the control system is the electron beam energy spread (σE) and seed induced energy modulation (ΔE) necessary to know A. These quantities can however be estimated for a given seed laser intensity with a dedicated measurement and fitting algorithm. Once A is measured for a given seed laser setting it is possible to estimate and control it by acting on the seed laser energy that is one of the accessible parameters for the seed lasers.

EEHG MODEL AND CONTROL PANEL

A high-level software with graphical user interface has been implemented to allow calculating and setting the right parameters to the FEL based on the required FEL wavelength. The tool (Fig. 6) is connected to the FEL via the tango control system and can read and write the required parameters upon request. The panel is planned to be able operating the FEL in both EEHG or HGHG using either $seed_1$ or $seed_2$, but at the moment only the EEHG section has been finalized and tested.

EEHG parameters used by the program are:

- wavelength of the two seed lasers (λ_1, λ_2)
- dispersion of the two chicanes (R_{56}^1, R_{56}^2)
- EEHG parameters N and M
- Amplitude of the seed laser modulation normalized to the energy spread (A_1, A_2)

Some of these parameters have a fixed value other can be varied in a given range based on the existing hardware.

$Seed_1$ laser in the case of FERMI is a fixed wavelength and cannot be varied. FEL tunability is only possible via tuning of the $seed_2$ laser wavelength, the accessible tuning range is an information available in the control system and specified by the laser experts.

Dispersion of both chicane can be varied in a large range but for sake of simplicity R_{56}^1 is normally set at a nominal value. The same for the A_1 that is normally kept fixed to a value in the range between 3 and 4.

If a new FEL wavelength is required the program calculates all possible solutions for generating that wavelength with the given parameters. In of more than one solution associated with different N and M or different $seed_2$ wavelength they are ordererd based on bunching level and required wavelength change of the seed. Only solutions that can be accessed with the given hardware (seed laser power, R_{56} strength) are showed. For the chosen solutions the predicted bunching at all possible wavelengths is plotted.

CONCLUSION

A new tool has been developed at FERMI for operating the new EEHG setup in FEL-1.

ACKNOWLEDGEMENTS

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