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BEAM BASED ALIGNMENT OF A SEEDED FEL

E. Allaria†, A. Brynes, B. Diviacco, L. Giannessi[1] and C. Spezzani
Elettra-Sincrotrone Trieste S.C.p.A. Trieste, Italy
[1]also at INFN LFN, Frascati, Roma, Italy

Abstract

Optimal FEL gain in a seeded FEL requires the careful alignment of different components. As for SASE FELs, the gain is optimized when the electron bunch travels in a straight line along the axis of each undulator in the radiator section. We have recently developed an alignment strategy for the optimization of the FERMI FELs which combines the beam-based alignment of the magnetic elements (undulators and quadrupoles) with the collinear alignment of spontaneous emission from each undulator. The method is divided into 3 steps. In the first step, we measure the undulator spontaneous emission with a spectrometer to fine-tune each undulator gap and set the best electron beam trajectory for collinear emission of each module. In the second step, the alignment of the undulator axis on the electron trajectory previously defined is achieved by looking at the undulator focusing effect. Finally, the seed laser is superposed on the electrons and aligned to maximize the bunching along the defined direction. This procedure can lead to an improvement in the control over the electron beam trajectory and results in a more efficient FEL process characterized by more stable and larger energy per pulse and a cleaner optical mode. A description of the method with the obtained results are reported in this work.

INTRODUCTION

High gain single pass Free Electron Lasers such as FERMI [1] rely on the energy exchange between the electron beam and the FEL radiation occurring along a long radiator (~ 100 m) composed of several undulators. To optimally couple the electrons to the radiation several conditions need to be satisfied:

1. Electron trajectory should be straight;
2. Resonance condition to the FEL wavelength should be met in each undulator;
3. Undulator need to be aligned to the electron beam axis.

In case of seeded FEL such as FERMI it is also required that:

4. the seed laser is aligned to the same electron beam axis.

Due to the strong interplay between these conditions, it is required to establish a procedure that allows to individually adjust each of them. It has been observed that the emission mode of a seeded FEL is strongly affected by the pointing of the seed laser [2]. With the procedure recently implemented at FERMI the first 3 points are cured before the seed laser is aligned.

† enrico.allaria@elettra.eu

DEFINING THE BEAM TRAJECTORY

FEL pulses produced by both FEL lines at FERMI can be characterized using the PADReS setup [3,4] accounting various optical elements and diagnostic including a spectrometer and various FEL profiles relying on YAG screens and CCD (Figure 1).

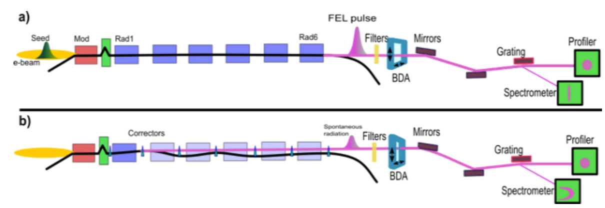

Figure 1: FEL-1 line and the used devices for the characterization of the FEL (top) and for the trajectory alignment procedure (bottom).

To define the straight trajectory on the long radiator, we use PADReS diagnostic on the spontaneous emission produced by the electron beam on a single undulator tuned at the desired wavelength while other undulators are open.

The PRESTO spectrometer collects the light dispersed in the horizontal plane by means of a diffraction grating onto a 2D detector, providing simultaneously the spectral distribution of the source (horizontal projection) and its intensity profile (vertical projection).

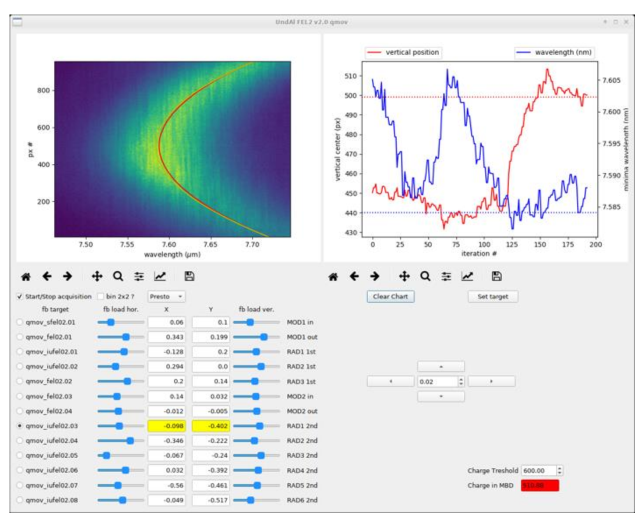

Figure 2: GUI used to monitor the evolution of the spontaneous emission mode while changing the trajectory in the resonant undulator.

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The spontaneous emission appears in a typical C-shape (as show in Fig. 2) corresponding to a vertical cut of the undulator emission cone integrated over the beam defining aperture (BDA). This shape reflects the quadratic relationship between wavelength and angle of deviation from the axis contained in the resonant condition equation for the emission from an undulator. The minimum of the parabola identifies the emission axis. In order to improve the accuracy, we set the BDA to a very small horizontal opening.

In these conditions a wavelength shift of the transmitted radiation is measured in PRESTO as the horizontal pointing of the electron beam is varied in the resonant undulators (blue line in Fig. 2 right panel). The shortest wavelength corresponds to the radiation mode centred to the BDA. In the vertical direction BDA are left open and changes of the electron beam trajectory will lead to vertical movements of the measured spectrum (red line in Fig. 2 right panel).

The procedure starts with the first radiator. The radiation wavelength is minimized with horizontal kicks to the electron trajectory and vertical trajectory is optimized to centre the radiation mode into the detector. The radiation mode (position and wavelength) is then taken as a reference.

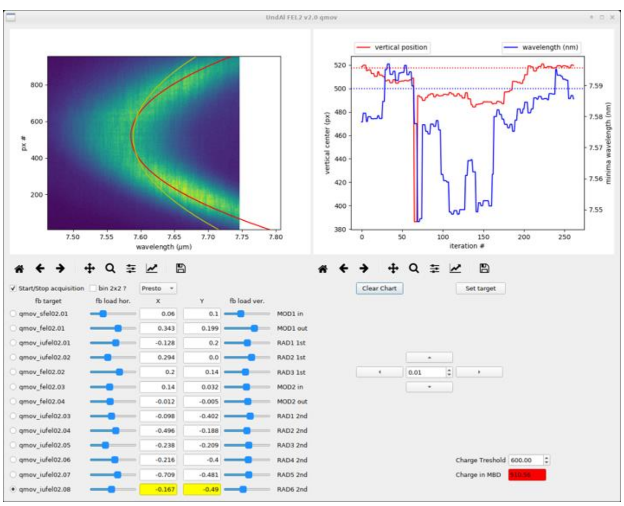

Figure 3: Alignment of the radiation mode of last undulator to the mode from one upstream.

The first undulator is then open and second one is put on resonance. Again, trajectory on rad 2 is adjusted (without changing trajectory on radiators upstream) to find minimal wavelength (horizontal) and nominal pointing (vertical).

Trajectory is moved by changing the target position on the beam position monitors (BPM) downstream the interested undulators, the trajectory feedback adjust the correctors to keep trajectory unchanged everywhere except the desired BPM. If after the optimization a wavelength shifts exists between the two undulators, an offset to the undulator gap is used to have the same resonant wavelength. Accuracy of the procedure is of the order of 10 µm for the trajectory and 5 µm for the undulator gap.

One after the other, the trajectory of the electron beam in all undulators is optimized.

A successful alignment of the electron beam trajectory leads to an improved FEL performance with larger stability and a nicer transverse mode of the FEL spot as measured in the profiles (Fig. 4).

A typical side effect of a well-defined straight trajectory is that most of the correctors used by the feedback are relaxed.

Current Limitations of the Procedure

Due to the need to work with spontaneous emission that from single undulator is very weak the method requires the availability of a very sensitive detector in the spectrometer. The method can only be done using an in vacuum EUV camera. Moreover, due to the need to have the full “c” shape measured by the detector the method only works for relatively short wavelength (<15 nm).

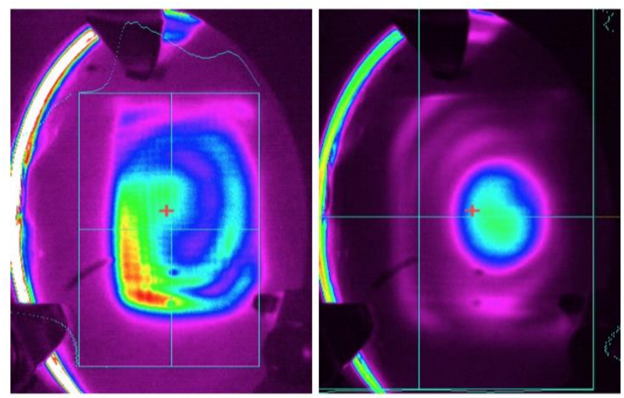

Figure 4: FEL spot profile before (left) and after (right) a successful alignment procedure. To be noted that the CCD gain has been reduced.

For FEL-1 it has been possible to apply the method looking at the emission mode of the third harmonic of the resonant wavelength with the undulator set in horizontal polarization.

Given the need to work at short wavelength the method also requires the undulators to work at relatively large gap. As a result, the method may not take into consideration the undulator focusing that may occur in case of an undulator not aligned with the electron beam axis and operated a smaller gap.

In order to verify and possible solve this a second procedure has recently been implemented.

UNDULATOR ALIGNEMENT

The relative alignment of the undulators to the defined nominal electron beam trajectory is estimated by measuring the kick produced by the undulators to the electron beam when closing the gap.

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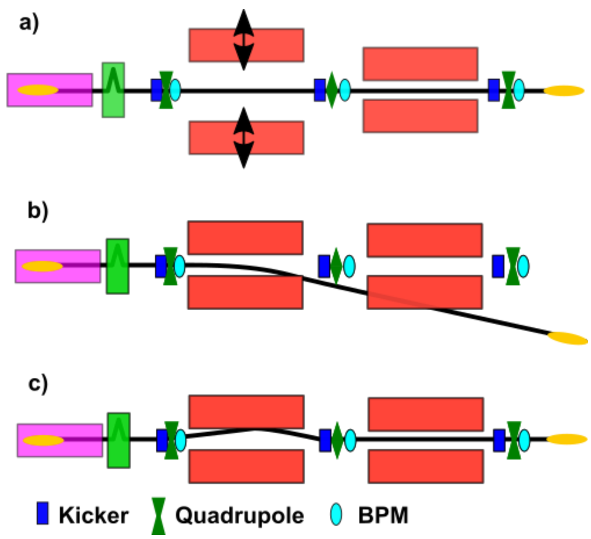

Figure 5: Scheme used to measure the undulator offset with respect to the electron beam trajectory. a) straight trajectory with undulator open. b) Undulator induced kick on the trajectory. c) Kick compensated by the feedback.

Instead of estimating the undulator induced kick by measuring the induced beam offset in the two downstream BPMs (Fig. 5b) the procedure implemented at FERMI uses the measured strength of the correctors (upstream and downstream of the undulator) required to keep the trajectory at 0 in all BPMs (Fig. 5c). The strength of the corrects is measured as a function of the undulator gap (Fig. 6).

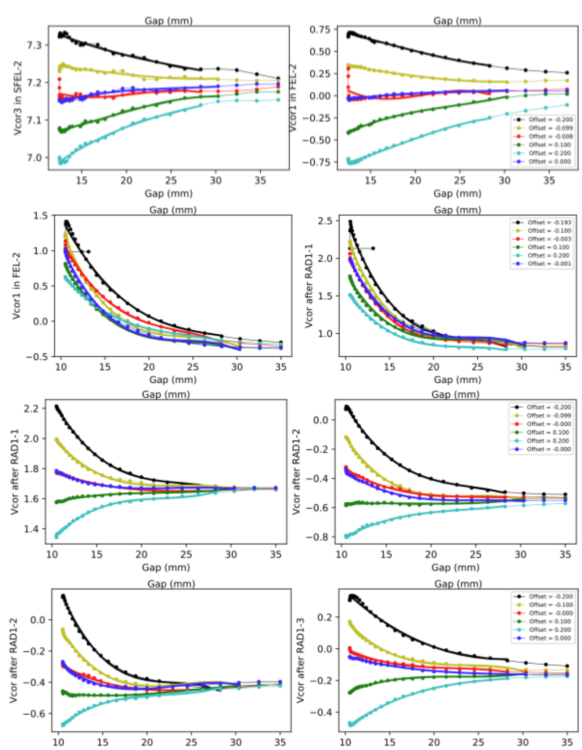

Figure 6: Measurements done on the modulator and first 3 radiators of FEL-2 for five different values of the undulator vertical offset.

The measured undulator kick is the result of a combination of residual field integral and undulator focusing. An accurate discrimination between the two effects in not straightforward and not yet implemented, nevertheless looking at the decay of the corrector strength occurring over the range of ~10 mm gap it is possible to estimate the effect of undulator focusing. Repeating the measurement with different values for the undulator axis it is possible to identify which axis has a minimum impact on the electron beam. The procedure is repeated for each undulator.

FERMI undulator design allows to change the undulator axis in the vertical direction adding an offset of up to 500 µm. The same measurement can be done also by moving the electron beam axis in the whole undulator area, this is done using the quadrupole movers that move both the BPM and the quadrupoles so that the beam is always passing at the centre of the quadrupoles and no extra kick from the quadrupoles is added. By using this second option it has been possible to measure both the vertical and the horizontal alignment of the undulators with respect to a nominal trajectory.

For the APPLE-II radiators of FERMI measurements can be repeated for different polarizations, this could allow an easier discrimination between the residual field integral and the undulator focusing due to the misalignment.

Recently the method has been tested on both FEL-1 and FEL-2. Measurements on FEL-1 show small residual offsets of the radiators with respect to the nominal trajectory, typically one or two undulator can have a maximum offset of less than 100 µm. Correction of the offsets has not shown a significant improvement of the FEL, but more systematic studies need to be performed.

Measurements on FEL-2 instead showed a large offset of one of the radiators of the first stage (Fig. 6 second panel), while downstream undulator appears to be aligned within 50 – 100 µm. Results from rad1-1 suggests that the undulator has an offset of about 500 µm. The large offset between the rad1-1 axis and the closest undulator has been confirmed by laser tracker measurements.

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