MULTIPLE FELS FROM THE ONE LCLS UNDULATOR*

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Abstract

The FEL of the Linac Coherent Light Source (LCLS) at SLAC is generated in a 132 m long undulator [1]. By introducing a kink in the undulator setup and launching different electron pulses with a small kick, we achieved two FEL beams with a separation of about 10 σ. These beams were separated at downstream mirrors and brought to the entrances of the soft and hard X-ray hutches. This was done at low energy creating soft X-rays which require only a shorter length to get to saturation. At high energy the whole undulator has to be "re-pointed" pulse by pulse. This can be done using 33 undulator correctors creating two straight lines for the photons with small angle to point the FEL to different mirrors pulse by pulse even at high energy. Experiments will be presented and further ideas discussed to get different energy photons created and sent to the soft and hard X-ray mirrors and experiments.

PRINCIPLE OF MULTIPLE FELS

The principle driving idea is to make the expensive 132m long LCLS undulator, which consists of 33 girder modules, usable for different experiments at the same time. This can be achieved by introducing a kink in the long undulator (or a fast repointing of the whole undulator, see later) and pointing one of the two FEL beams produced with the different angle to a separating mirror downstream, while the other just passes by it (see Fig. 1).

Other approaches are to split the light of one FEL beam AFTER the undulator for instance by a Large Offset Monochromator near the hutches, or split the electron beam BEFORE the undulator and pass it through different undulators. This approach is used for LCLS-II.

Here we will discuss the approach to use the undulator itself to make and start separating the two FEL beams. The advantages and pitfalls are discussed, and some experiments presented.

EARLY EXPERIMENTAL TEST

Initial tests with using one electron beam and bend it into the second part of a kinked undulator showed that also two FELs were produced (Fig. 2), but with some undesirable characteristics. By separating the beams too much the lasing of the second part was suppressed. Also the intensity of the two beams was strongly anti-correlated, indicating that the electron beam after giving enough power to the first FEL beam is too much disturbed to give enough power to the second FEL, and vice versa. The advantage of this setup would be the full rate of 120 Hz to two experiments.

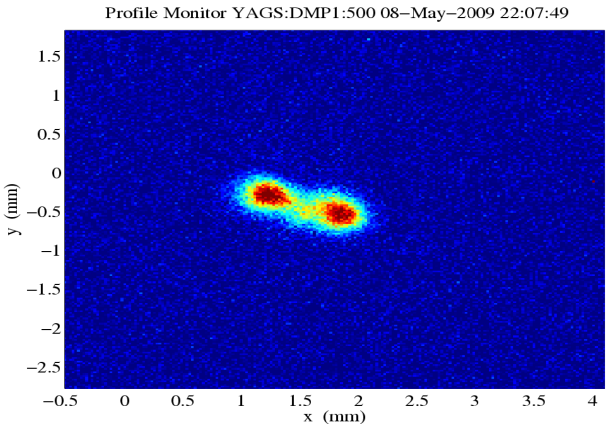

Figure 2: Two FEL spots from one bunch have anti-correlated intensity.

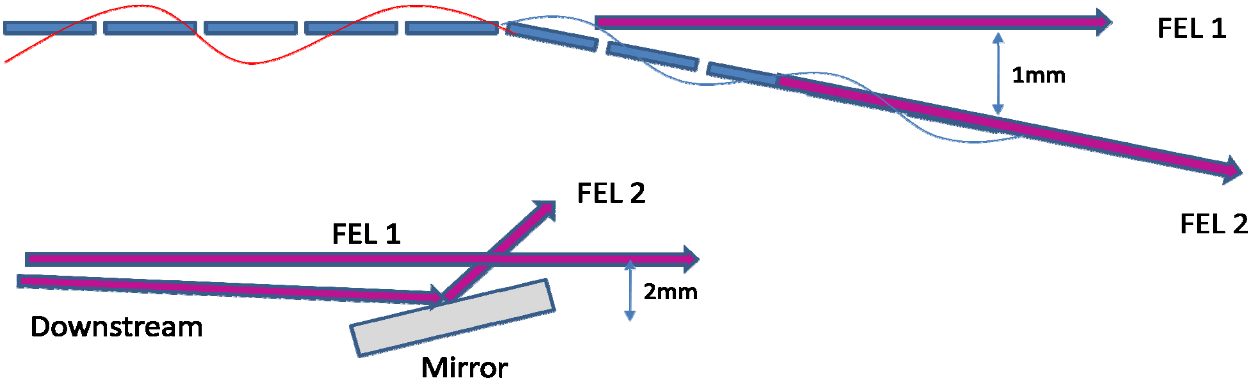

Figure 1: Principle to get two FELs out of one undulator: The undulator has a small kink in the middle so the FEL light of the first part and the second part is about 1 mm apart at the exit of the undulator and about 2 mm at a downstream mirror, which separates the beams further. By kicking some electron pulses (red) they will only lase in the second half, while the un-kicked pulse (blue) lases only in the first half and oscillates too much for lasing in the second half.

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SETUP WITH TWO DIFFERENTLY PULSED ELECTRON BEAMS

The early test showed that the electron beam should be undisturbed by micro-bunching to produce stable lasing in each of the two undulator parts. This can be achieved by two “fresh” electron bunches for these two parts. In general two bunches in the same RF pulse and a fast kicker of the order of tens of nanoseconds would accommodate twice120 Hz running. Here we describe a scheme were the pulse rate was split between the two FEL beams on a millisecond scale, like 1 and 9 out of 10 Hz, or 6 and 4 Hz out of 10 Hz.

Pulsed Correctors

A system was installed in the Linac-to-Undulator region (LTU) to allow fast (ms) air core correctors to be pulsed on a pulse by pulse basis to correct noise up to 120 Hz. This system also allows putting in nearly any timing pattern. Initially 60 Hz was split into 30 / 30 Hz, but the camera systems which work only at 10 Hz or less couldn’t identify the second spot. So we went to 10 Hz and split it in a 1 / 9 Hz and 6 / 4 Hz fashion for the non-kicked and kicked beams. The set point offsets of the fast feedback have to be adjusted for the kicked beam till the further downstream trajectory in the second half becomes flat.

Figure 3 shows the trajectory for these beams in the undulator, where an orbit variation of 50 µm or more suppresses lasing, so the blue (1 Hz) beam lases only in the first half while the red (9 Hz) beam lases in the second half.

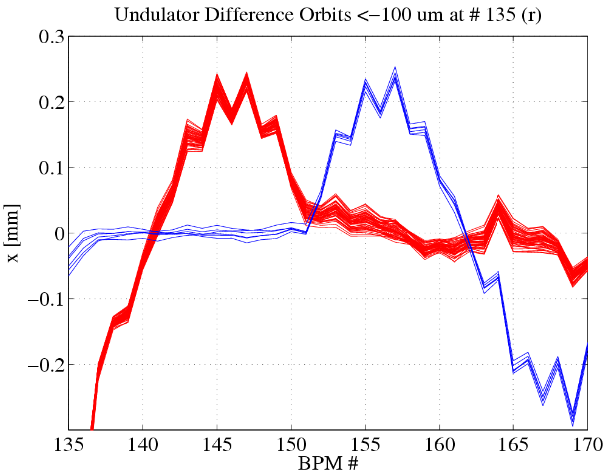

Figure 3: Non-kicked (blue) and kicked (red) beam trajectory in the undulator (BPMs # 137 to # 170).

Undulator Setup

The undulator was setup by kinking the undulator at girder 14 so that the end moved -800 µm (like in Fig. 1), then the whole undulator was moved by +500 µm. This helps that the produced FEL light can pass through 4 mm diameter downstream apertures (Fig. 4). The quadrupole at girder 14 was not moved to kick the blue beam into the kinked direction, so it starts to oscillate from then on, red beam was set up so it comes in with an oscillation, which gets cancel at undulator girder 15.

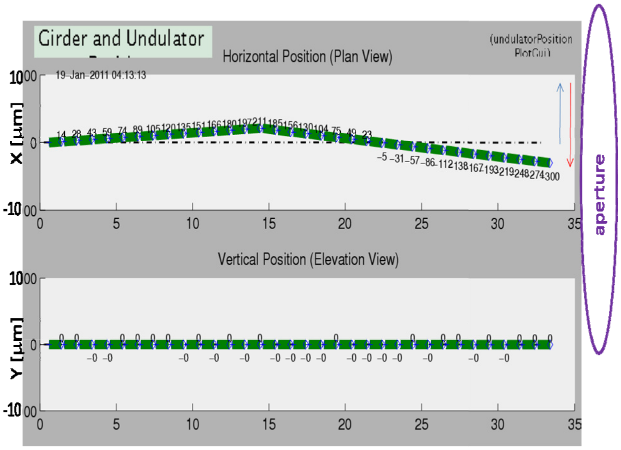

Figure 4: The undulator horizontal pointing has a kink at girder 14, the middle of 28 actively used girders.

Profile Monitors

Downstream of the last undulator by 87 m there is a YAG screen (Direct Imager), where the two spots of the FEL are visible separated by 1.6 mm (nearly 10 σ, Fig. 5). They are centered inside the available aperture of about 4 mm.

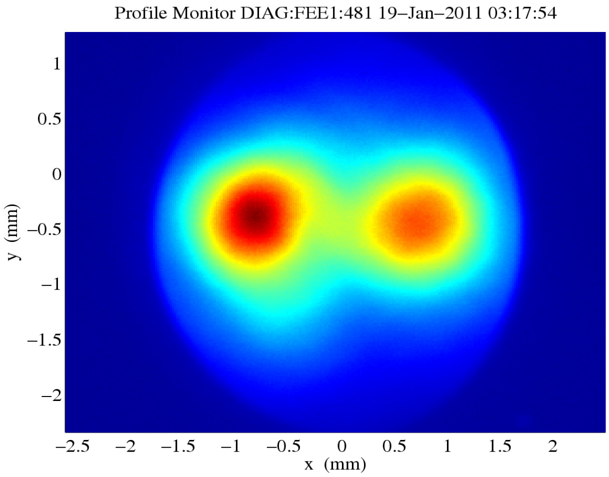

Figure 5: The Direct Imager shows two beam spots with 6 and 4 out of 10 pulses about 90 m after the undulator.

The next screen (P1) shows the beams at the splitting point, in Fig. 6 (top) before moving in the soft x-ray mirror and in Fig. 6 (bottom) after the mirror separated the two beams. Further downstream after two more mirrors one beam sits just in front of one of the soft x-ray hutches (AMO) on the third pop-in monitor P3S1 (Fig. 7), while the second beam gets clipped by two hard x-ray mirrors in x and appears in front of the hard x-ray hutch XPP on P3H (Fig. 8).

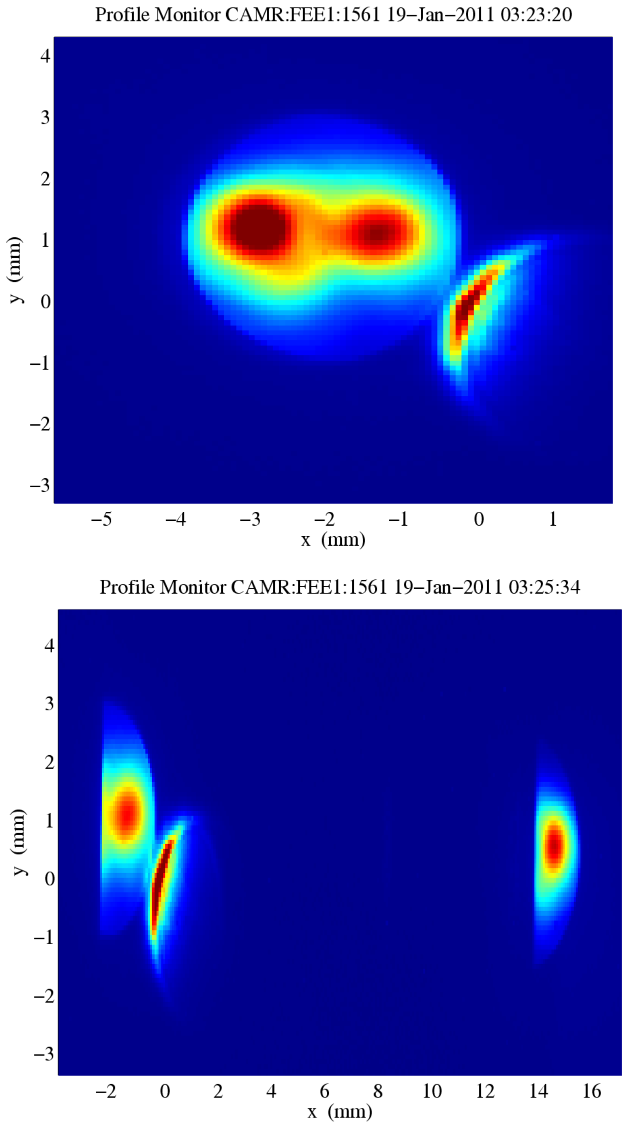

Figure 6: The top shows the two beams at the splitting point (P1) still together since the mirror is out of the way. (The half-moon shaped part is a reflection of the wall). In the bottom picture the mirror is moved in from the left to about -3 mm, which reflects the left beam spot into the soft x-ray beam line and appears here at +14 mm.

MULTIPLE FELS AT HIGH ENERGY

At high energy the whole undulator has to be used to produce the maximum FEL intensity. For re-pointing the undulator we mechanically move the girders including the undulator with beam pipe and the quadrupoles to define a straight line. But there is another way how to get a straight by using corrector windings, which are at the quadrupole location. An offset beam in a quadrupole gets a kick, which can be exactly with its corrector generating a straight line for the electron beam to follow. Figure 9 shows the principle of this setup.

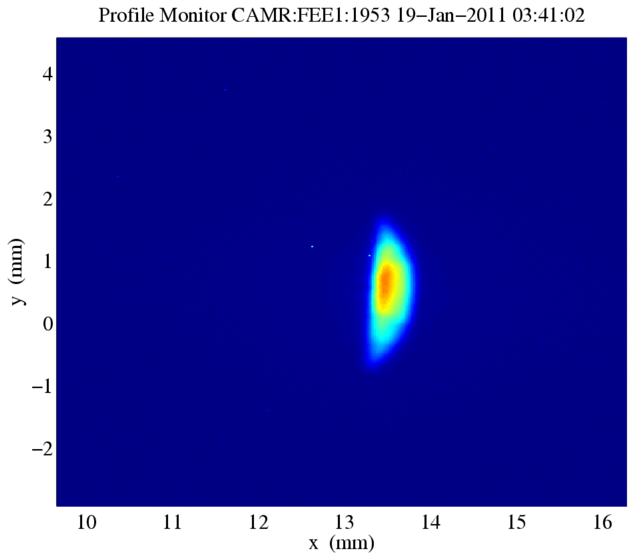

Figure 7: One of the beams at the end of the soft x-ray line in front of the AMO hutch.

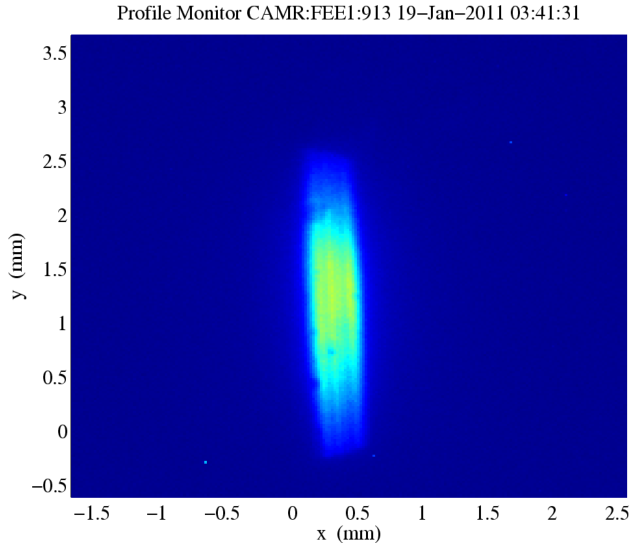

Figure 8: The other beam at the end of the hard x-ray line in front of the XPP hutch.

Now we have to look into the effects of being not centered in the undulator and beam chamber. The wakefields created in the vacuum pipe will be not symmetric, and the undulator K-value will slightly change in x and quadratically in y (see Fig. 10).

Fast Correctors

A test was done which showed that the current response time of the power supplies is too slow for this setup and needs some modifications. The laminated quadrupoles magnets with it corrector coils might be fast enough to support these fast changes.

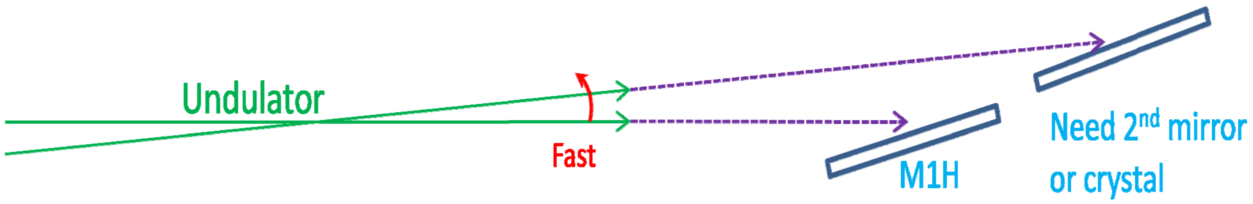

Figure 9: The undulator can be re-pointed at 60 Hz or less with 33 pulsed correctors without moving the undulator girders, quadrupoles or beam pipe. This would facilitate two hard x-ray FEL beams.

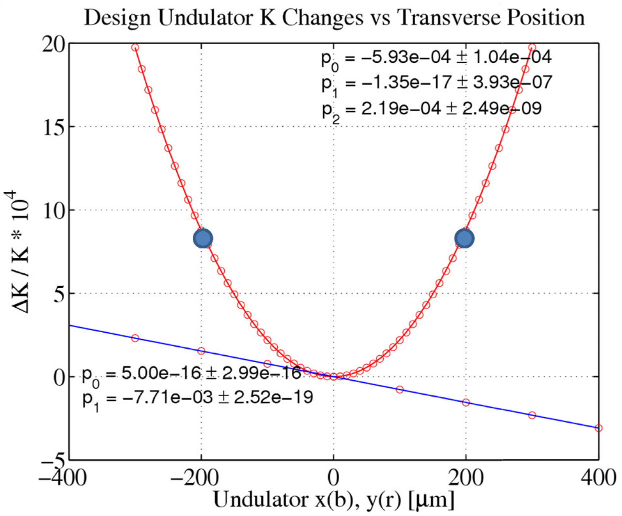

Figure 10: Calculated undulator *K* changes for *x* and *y* trajectory offsets. In *y* a symmetric offset of + and – 200 μm will have the same *K*, but give a strong *K* gradient.

SUMMARY

We have presented different scenarios how to get multiple FEL beams out of one undulator, pointing in different direction, so that they can be separated by downstream mirrors.

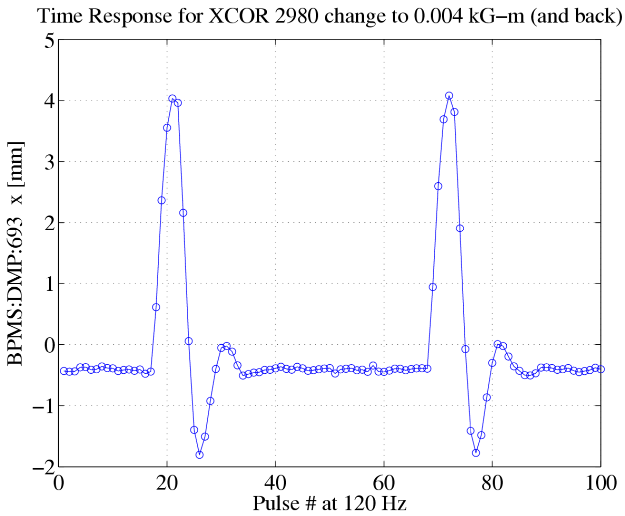

Figure 11: The current response time is to slow for this scheme to work and needs a modification of the corrector modules.

REFERENCES

[1] P. Emma et al., “First Lasing and Operation of an Ångstrom-Wavelength Free-Electron Laser”, Nature Photonics, Aug 2010.

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