DOUBLE-PULSE GENERATION WITH THE FLASH INJECTOR LASER FOR PUMP/PROBE EXPERIMENTS

Oliver Grimm*, Karsten Klose, Siegfried Schreiber, DESY

The vacuum ultraviolet and soft X-ray free-electron laser FLASH at DESY, Hamburg, will be complemented with an infrared undulator working in the wavelength range 1 to 200 µm by summer 2007 [1, 2]. This powerful infrared source, naturally synchronized with the FEL, will be well suited for pump-probe experiments. Construction constraints of the infrared beam line will result in an optical path length about 80 cm (2.7 ns) longer than for the VUV. Combining IR and VUV radiation from the same bunch in a pump-probe experiments is in principle possible by delaying the VUV using normal-incidence multilayer mirrors. Such mirrors, however, are tailored to a specific, narrow wavelength range and don't have a particular high reflectivity.

A more general option to allow pump-probe experiments at all wavelengths is accelerating two electron bunches such that the IR from the first and the FEL pulse from the second electron bunch arrive simultaneously at the experiment.

CONCEPT

The FLASH injector laser consists of an 27 MHz oscillator working at 1047 nm, diode and flashlamp pumped amplifiers, 1 MHz pulse pickers, and two frequency-doubling stages using LBO and BBO crystals. The final wavelength is 262 nm. The laser is guided to the photocathode using relay imaging.

The concept of the pulse doubler consists in splitting, delaying and recombining the pulses in the ultraviolet, just before they are transported to the photocathode, as sketched in Fig. 1.

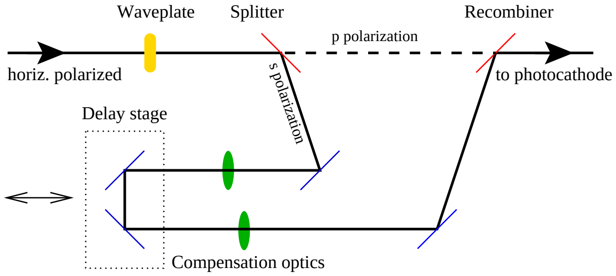

Figure 1: Concept of the laser pulse doubler.

The incoming radiation is horizontally polarized. The first element is a $\lambda/2$ waveplate, allowing an arbitrary rotation of the plane of polarization. The following beam splitter is a coated fused silica plate oriented at the Brewster-angle (about 56°), transmitting 94% of the horizontal polarization component (p polarization), and reflecting 99.7% of the vertical polarization to the side. The relative intensities of the transmitted and the reflected beam can thus be adjusted by rotating the $\lambda/2$ plate. The reflected pulse is delayed, and then both pulses are recombined using the same type of Brewster-angle beam splitter. The previously transmitted component is again transmitted, likewise for the reflected component, so the efficiency is high. With a non-polarizing splitter 50% of the intensity would be lost due to unwanted transmission and reflection at the recombiner.

Because of the complementary orientation of splitter and recombiner, the lateral offset that the direct beam acquires after passing the splitter is compensated by the recombiner, thus the direct beam can serve as alignment reference if it was correctly aligned prior to the installation of the pulse doubler. In practice, the two beams are first brought to an overlap on the recombiner, which is then slightly tilted to achieve co-propagation of both.

The laser transport line provides for the correct transverse shape on the photocathode, essential for a low emittance and, in turn, for achieving lasing. The additional path length of the delayed pulse is compensated by two lenses arranged as for a Keplerian telescope with unit magnification. For a focal length f, the compensated path length is therefore $4f$.

MACHINE SET-UP

An important step in setting up FLASH for lasing requires fine adjustments of all accelerating module phases to better than 1°, for some phases to about 0.1°. With double pulses, this precision is necessary for the second pulse that should provide FEL radiation.

Set-up of the pulse doubler starts from a machine already set-up for lasing with single pulses. After inserting the doubler components, the polarizer is first adjusted for maximum intensity of the direct pulse. A small increase in laser power is necessary to compensate losses and to achieve the same bunch charge as before. All module phases need then to be changed by a few degrees to recover lasing due to the extra delay the laser pulses get in the silica glass substrates of polarizer, splitter and recombiner. The polarizer is next rotated for maximum reflection at the splitter, and the laser power again slightly adjusted to get the same bunch charge for the delayed pulse.

The delay of this pulse is roughly adjusted to 100 ps (approx. 45° of the 1.3 GHz RF) using a fast photodiode. The

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[*] Corresponding author, e-mail: oliver.grimm@desy.de

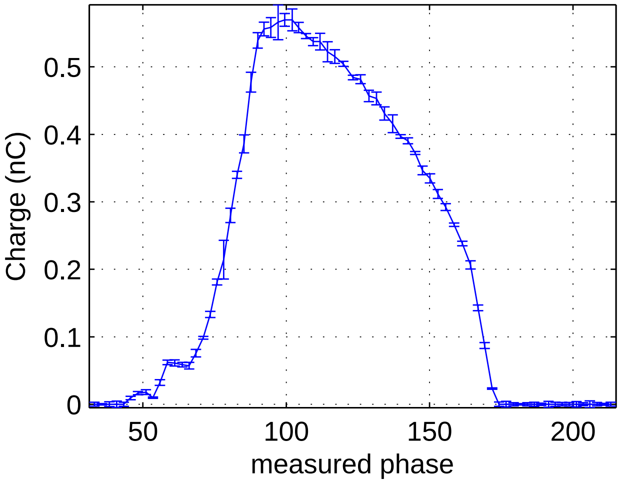

Figure 2: Scan of charge versus accelerating phase. Zero field crossing is at 175°, on-crest phase at 85°.

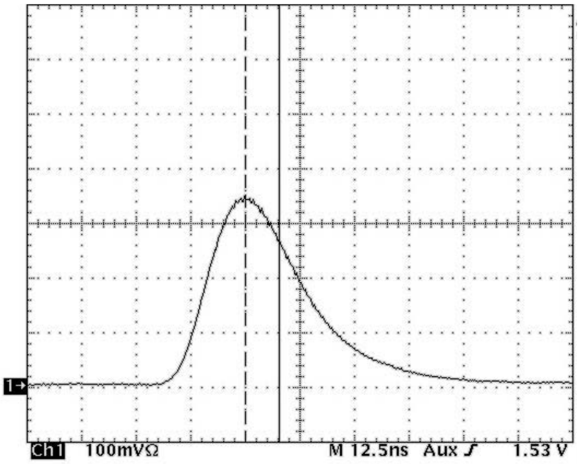

Figure 3: Analogue signal from a toroid for a single pulse. The cursor separation corresponds to 8 RF periods.

charge measured by the first toroid in the machine is then scanned versus the RF phase, see Fig. 2 for an example. The best defined point of such a scan, the beginning of the appearance of charge at electric field zero crossing, is adjusted to the same phase as for the direct pulse to about 1° accuracy. Final fine tuning of the delay and module phases to achieve lasing is then performed, just as for normal operation. 1° corresponds to a path length difference of 641 µm, so the phase can be adjusted very precisely using a standard linear stage. Currently, the delay adjustment is done manually on the laser table, but a fully motorized version is planned for the future.

EFFECT OF DOUBLE PULSES ON DIAGNOSTICS INSTRUMENTATION

The instrumentation of FLASH is designed to operate at the future maximum bunch frequency of 9 MHz. Bunches separated by only (10–15) ns can not be resolved by most diagnostics, although their operation can be disturbed. Therefore it is important to understand the reading from the various instruments for the two cases of having only a delayed pulse, and having both direct and delayed pulse in the machine.

As an example, the analogue signal from a toroid is shown in Fig. 3. The standard ADC timing is set such that it is sampled at the peak. A delayed pulse will result in an equivalently delayed signal from the toroid that will then be sampled on the rising edge.

The ADC sample timing can be shifted in units of 4 ns, so if only the delayed pulse is present the sampling can be always set to almost peak. If both direct and delayed pulse are present, the resulting analogue signal is the sum of both, so that the value sampled by the ADC will depend on the delay and on the relative amplitude of both pulses. Knowing these, the value read form the ADC can be corrected for the true value.

Various types of beam position monitors (BPM) are used at FLASH. For button-type and stripline BPMs the read-out electronic is based on amplitude-modulation/phase modulation transformation [3].

The short pulse generated by a button-type BPM is, after transformation, stretched to 4 ns, fed into a sample-and-hold circuit and then digitized. Most BPMs of this type are externally triggered and register only the bunch at trigger time. Two self-triggered devices in the injector register always the first bunch, regardless if it is a direct or delayed single pulse, or the first on a double pulse. They have problems, however, when the combined charge of both pulses is too large.

The signal from a stripline BPM is passed through a 375 MHz ringing filter, and the amplitude of the resulting sine-burst is then transformed to phase in a similar manner than for a button BPM. The time-scale is, however, longer, so that contributions from both pulses on a double pulse influence the final reading from the device.

The quality factor of the 1.5 GHz cavity BPMs is about 1000, so that these operate on a comparatively long time scale and will thus mix the two pulses. Read out is accomplished by downmixing with a second 1.5 GHz frequency that is synchronized with the normal bunch trigger. As the phase relationship of the two pulses with respect to the 1.5 GHz depends on their separation, the final reading from a cavity BPM depends on this separation as well. As a bunch passing on axis does not excite the dipole mode used for position measurement, a zero reading should still be correct also for the double bunch unless the phase difference happens to result in fully destructive interference.

The basic SASE intensity monitors, a multi-channel plate registering scattered photons from a wire grid and a gas ionization detector, are insensitive to the double pulse separation on the time scale of 10 ns and indicate the total intensity.

FIRST RESULTS FROM FEL OPERATION

First attempts to get lasing of FLASH with double pulses have been made during dedicated machine time in June 2006. The main concern here was to maintain the high electron bunch quality in terms of emittance and longitudinal profile that is needed for the SASE process. With two pulses of similar charge instead of a single one the beam loading is doubled for the accelerating modules. Additionally, the second pulse is subject to wakefields from the first.

The experiments followed the scheme outlined above for machine set-up. A delay corresponding to 12 periods of 1.3 GHz (9.23 ns) was chosen. After aligning the delayed beam by means of the virtual cathode (a scintillator viewed by a camera that precisely reproduces the position of the actual photocathode with respect to the laser beam optics) and adjusting the charge of the delayed pulse to the same value used for single pulse operation, SASE was found immediately, with almost full recovey of the previous, single-pulse level after some fine tuning.

After unblocking the direct pulse as well, lasing was achieved without further adjustments for both pulses, such that beam loading and wakefield effects appear to have only little effect, if any, at this double pulse separation. The phases of the accelerating modules were found to be effective in adjusting the relative intensity of both SASE pulses while keeping the combined pulse energy almost constant. An example for a signal from a fast photodiode, registering SASE radiation scattered by a wire grid, is shown in Fig. 4. The amplitude response of the photodiode is close to proportional to pulse energy, so that here the delayed pulse had about 60% of the intensity of the direct one. Also tunig for an reverse intensity distribution was possible.

Successful lasing of both bunches of a double pulse was achieved for one single double pulse, as well as for 10 double pulses, and at wavelengths of 15 nm and 32 nm. Due to the good stability of the machine, the partial or complete disfunctioning of some basic beam diagnostics had no detrimental effect for these first studies. Future efforts will concentrate on increasing the pulse energy of both pulses, if possible up to SASE saturation.

CONCLUSION

The possibility of accelerating double bunches in the FLASH accelerator, separated by several periods of the 1.3 GHz driving radio frequency, has been demonstrated. Lasing on the 10 µJ level was achieved for both bunches simultaneously. The main motivation for implementing such a scheme is the infrared/VUV pump-probe facility to become operational in summer 2007 which requires special beam preparation due to the longer path length of the infrared radiation to the experimental station. Further interesting pump-probe experiments could be undertaken if lasing from both bunches at slightly different wavelengths is achievable [4]. This requires accelerating both pulses at slightly different phase, thereby affecting their energies. Pulses of different wavelength can then be spacially separated by means of a suitable monochromator.

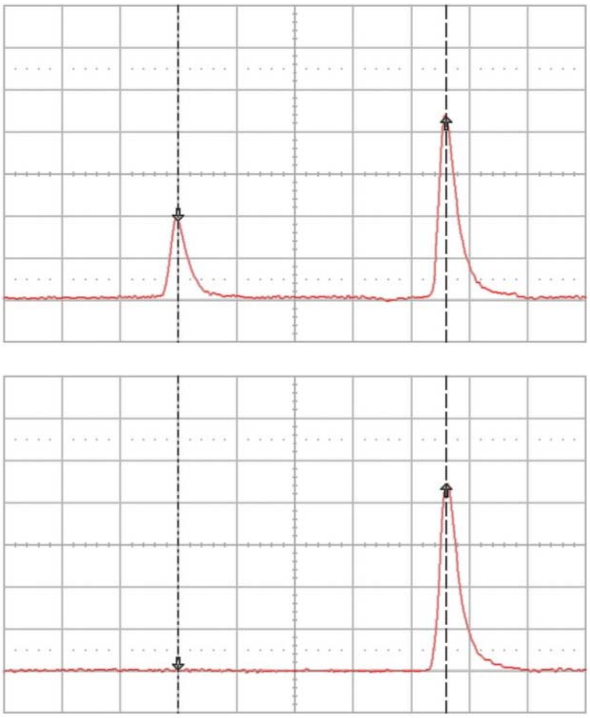

Figure 4: Signal from a fast photodiode for two SASE pulses separated by 12 RF periods at 1.3 GHz (9.23 ns, the separation of the cursor bars). One division is 2 ns horizontally, 5 mV vertically. The wavelength is 32 nm. For the lower plot the first (direct) pulse was blocked.

Acknowledgments

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