DEVELOPMENT OF A QUASI 3-D ELLIPSOIDAL PHOTO CATHODE LASER SYSTEM FOR PITZ*

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Abstract

Minimization of the electron beam emittance is the major strategy for optimizing a high brightness electron source. Pulse shaping of the photocathode laser is one of the main tools for optimization of modern photo injectors required for a successful operation of linac based free electron lasers. 3-D ellipsoidal photocathode laser pulses are now considered as the next step in the optimization of photo injectors operated in the space charge dominated regimes.

Significant improvements in electron beam emittance obtained from beam dynamics simulations using 3-D ellipsoidal photo cathode laser pulses, as compared to the conventional cylindrical pulses, have motivated experimental studies in order to develop a laser system for quasi 3-D ellipsoidal pulses.

The Institute of Applied Physics (IAP, Nizhny Novgorod, Russia) is developing such a photocathode laser system in collaboration with the Joint Institute of Nuclear Research (JINR, Dubna, Russia) and the Photo Injector Test facility at DESY, Zeuthen site (PITZ). Experimental tests of this system with photoelectron beam production are planned at PITZ. The laser pulse shaping is realized using spatial light modulators. The laser system is capable of pulse train generation and is currently being tested at IAP. The first cross-correlation measurements were done demonstrating the ability to generate and measure quasi-ellipsoidal laser pulses. In this contribution the overall set-up, working principles, and the actual progress of the development will be reported.

INTRODUCTION

In the last decades ultrafast spectroscopy has become a very attractive research field. Depending on the aim of the different experiments very short laser pulse durations of a few femtoseconds or shorter are required.

Wavelengths in the XUV are necessary for a lot of these experiments [1]. Such beams can be provided by linac-based Free-Electron Lasers (FELs) such as the Free-electron LASer in Hamburg (FLASH) and the European X-ray Free-Electron Laser (European XFEL).

Both linacs operate on the basis of the Self Amplified Spontaneous Emission (SASE) process [2]. This process requires an extremely high space charge density of the radiating electron bunches. This requires high peak current, low energy spread, and small transverse emittance of the electron beam. The latter property cannot be improved in the linac and thus the emittance must be minimized in the injector.

Cathode laser pulse shaping is one of the main possibilities to achieve this. A significant reduction of the transverse emittance of space charge dominated beams can be achieved by utilizing a flat-top temporal profile of cylindrical pulses instead of Gaussian laser beams. The latter is the standard profile at most FELs.

At PITZ – where a flat-top temporal profile is used by default - measurements of the transverse projected beam emittance between 0.7 and 0.9 mm*mrad for electron beams of 1 nC have been obtained [3].

Based on independent simulations the next step towards further improvement is the use of 3-D ellipsoidal photo cathode laser pulses [4,5].

BEAM DYNAMICS SIMULATIONS

In order to illustrate the improvement of the beam dynamics using 3-D ellipsoidal laser pulses instead of cylindrical pulses with Gaussian or flat-top temporal profiles, simulations have been done for all three different temporal pulse shapes. The simulations were based on the PITZ photo injector layout [3]. The assumed diameter of the cathode laser beam was about 0.4 mm, the electron beam charge was 1 nC and the simulations were done evaluated at a distance of 5.74 m from the photo cathode.

The results of these simulations are shown in Fig 1. Here a clear advantage of 3-D ellipsoidal compared to cylindrical laser pulses with flat-top (or Gaussian) temporal profile can be seen. The reduction of projected emittance is about 32% (59%), the reduction of average slice emittance is 27% (44%). Further information about the beam dynamics simulations in general are presented at this conference by M. Khojoyan et al. [6].

3-D ELLIPSOIDAL PHOTOCATHODE LASER SYSTEM

Based on the simulations, a corresponding laser system capable of producing quasi 3-D ellipsoidal UV laser pulses is under development at the IAP in collaboration with JINR. Starting from autumn this year this laser system will be integrated and tested at the high brightness photo injector at PITZ.

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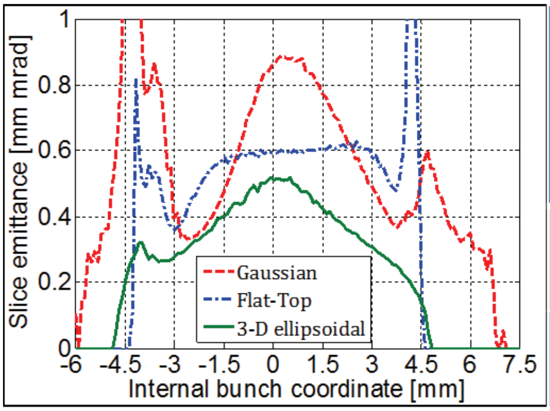

Parameter	Cathode laser pulse profile		
	flat-top	Gaussian	3-D ellipsoid
ε_{proj} [mm mrad]	0.63	1.05	0.43
$\langle\varepsilon_{slice}\rangle$ [mm mrad]	0.55	0.72	0.40

Figure 1: Beam dynamics simulation of electron bunches for photo cathode laser pulses with flat-top, Gaussian and 3-D ellipsoidal temporal profiles; left: normalized transverse slice emittance ε_{slice} distribution along the electron bunch, right: values of normalized transverse projected emittance ε_{proj} and normalized average slice emittance $<\varepsilon_{slice}>$.

The laser system consists of a dual-output fiber laser, a diode pumped Yb:KGW disk amplifier, a 3D pulse shaper, and frequency conversion crystals for the generation of second and fourth harmonics. A scanning cross-correlator system was developed and built to measure the spatial and temporal distributions of the laser pulses.

The dual-output fiber laser consists of an oscillator, which generates laser pulses at a wavelength of ~1030 nm with pulse duration of 150 fs at a repetition rate of 45 MHz, a fiber-based pulse stretcher, a preamplifier, and a system for pulse train (macropulse) formation. As precise tuning of the laser pulse timing to the RF phase of the gun is crucial for optimized operation of the photo injector a piezo ceramic cylinder has been integrated inside the optical fiber coil of the oscillator.

At the output of the fiber laser the generated beam is split into two beams – both equipped with separate fiber amplifiers. After amplification, temporal and spatial shaping, and frequency conversion the beam coming out of the primary output is used to illuminate the photo cathode. The characterization of this beam shall be done with the beam from the other output. After the fiber laser the pulses from the primary output, to be used for electron bunch generation, are amplified using a multi-pass Yb:KGW disk amplifier. A LDM 2000-100 (Laserline GmbH) is used as pump source. Currently micropulse energies up to 120 µJ can be obtained.

The amplified laser pulses are then shaped both temporarily and spatially. This is realized by a scheme based on Spatial Light Modulators (SLMs). The principle scheme of 3-D pulse shaping is shown in Fig. 2.
The pulse shaper is based on a zero dispersion optical compressor. Among other things, it consists of two diffraction gratings, two cylindrical lenses, and two liquid crystal based SLMs. The modulators are positioned on the focal planes of both cylindrical lenses, which images one diffraction grating onto the other in the meridian plane. There is no such imaging in the sagittal plane which implies corresponding diffraction. However, these effects can be neglected for the current 3-D pulse shaper set-up, with beam diameter of about 8 mm and focal length of the cylindrical lenses of 405 mm.

The first SLM manipulates the phase of the laser pulse. A half-wave plate is installed before the second SLM. This introduces a 45 degree rotation of the laser pulse

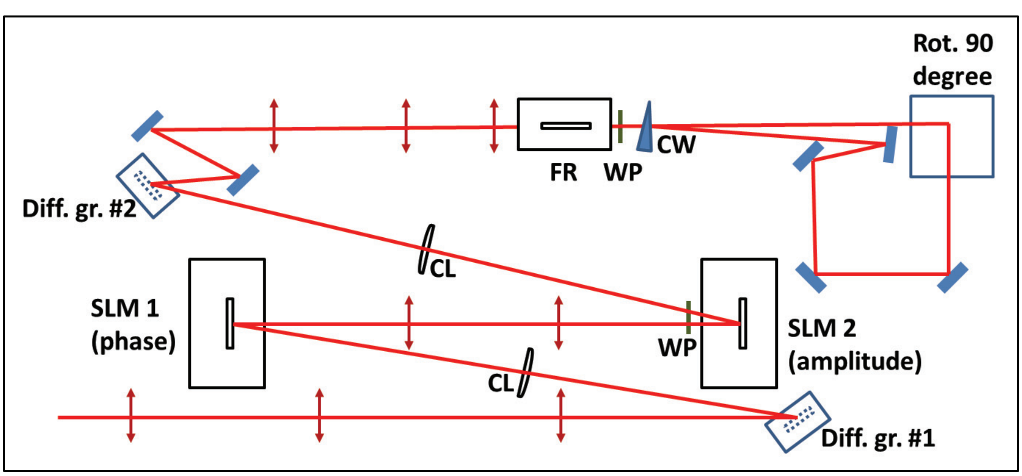

Figure 2: Setup of the 3-D pulse shaper: Diff. gr. – diffraction gratings, SLM – spatial light modulator, WP – half-wave plates, CL – cylindrical lens, FR – Faraday rotator, CW – calcite wedge, Rot. 90 degree – laser beam rotator (90°).

polarization and therefore the second SLM becomes an amplitude manipulator.

The laser pulse passes through the pulse shaper twice (Fig. 2). The first pass forms the laser profile in the x-plane and time, the second pass after a 90 degree rotation is responsible for the pulse shaping in the former y-plane and time.

Until now HES 6010 NIR SLMs (Holoeye Photonics AG) have been used for the pulse shaper experiments. Initial measurements with these SLMs have shown strong noise on the signals, which could not be significantly reduced by cooling of the SLMs or broadening of the liquid crystal matrix. New experiments using another type of SLMs - X10468-03 LCOS-SLM (Hamamatsu) - will start shortly.

The characterization of the 3-D shaped laser pulses is done using the scanning cross-correlator technique (Fig. 3). Therefore a high-speed delay line is implemented in the characterization beam line. This allows measuring the spatial and temporal profile of the micropulses with a high precision [7].

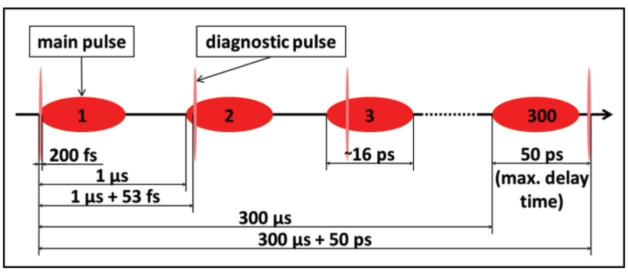

Figure 3: Time scheme of the scanning cross-correlator used for 3-D laser pulse diagnostics.

To get an intensity sensitive (nonlinear) signal related to the main pulse a 1 mm thick BBO crystal is placed, where the main and the diagnostic pulses intersect. To get the best temporal resolution the diagnostic pulses should be as short as possible. The minimum delay time between two diagnostic pulses depends on the number of micropulses within a macropulse and the pulse duration of the main pulse. In our case there are 300 micropulses at a repetition rate of 1 MHz within a macropulse and the main pulses have (zero-to-zero) pulse duration of 16 ps. That allows minimum time steps of about 53 fs. As mentioned earlier the pulse duration of the diagnostic pulses is longer – about 200 fs at the cross-correlator - so this length finally limits the time resolution.

Initial tests of the scanning cross-correlator were done with a simplified 3-D pulse shaper set up for quasi ellipsoidal pulse generation. Here (only) the amplitude mask of linearly chirped laser pulses at the fundamental wavelength of 1030 nm with pulse duration of 6 ps have been measured (Fig. 4). As can be seen, the scanning cross-correlation set-up provides the possibility to characterize laser pulses with a pulse duration of some picoseconds within 300 µs long pulse trains at a micropulse repetition rate of 1 MHz.

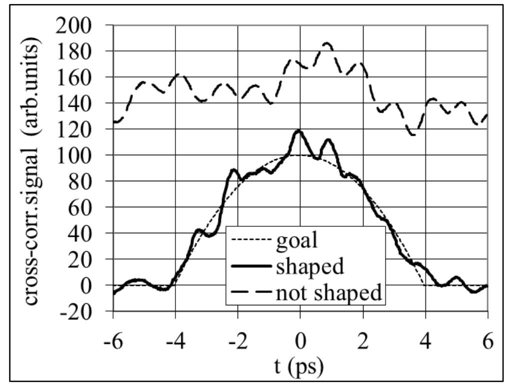

Figure 4: Scanning cross-correlator measurements of pulses w/o pulse shaping (dashed line), w/- amplitude mask pulse shaping (solid line) and aspired profile (dotted line).

CONCLUSION

On the basis of simulations it has been shown that a significant reduction of the emittance can be achieved using 3-D ellipsoidal laser pulses instead of Gaussian or flat-top temporal profile of cylindrical pulses. A possible laser set-up to create such 3-D ellipsoidal laser pulses was introduced. It was also shown that the characterization of these laser pulses is possible using the scanning cross-correlator technique.

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