Annual Report

Funding Programme:	**Helmholtz Joint Research Groups**
Project ID No.:	HRJRG-400
Project Title:	Application of 3D ellipsoidal cathode laser pulses for high brightness photo injector optimization
Principal Investigator:	Dr. Mikhail Krasilnikov (Helmholtz PI) Prof. Efim Khazanov (Russian PI)
Report Period (=Calendar Year):	01(07)/2013-12/2013

1) Group Structure

Please report briefly on the structure and personnel development of your group.

Helmholtz group (Germany):

DESY, Zeuthen site:

- Dr. Mikhail Krasilnikov (PI) general coordination, beam dynamics simulations, PITZ run coordination;
- Dr. Martin Khojoyan (postdoc at PITZ, DESY), beam dynamics simulations for various shapes of the photocathode laser pulse, optimization of the PITZ setup for the new laser shape, tolerances studies;
- Dr. Tino Rublack (postdoc at PITZ, DESY), photocathode laser expert, responsible for the PITZ laser room reconstruction, responsible for the new laser system tuning from DESY side;
- Two PhD students (funded by the project) are still not employed (the selection procedure is finished, hiring is ongoing)

Russian participants:

IAP, Nizhny Novgorod:

- Prof. Efim Khazanov (PI), general coordination, scientific supervision;
- Dr. Anatoly Poteomkin (senior researcher), scientific supervision, laser amplifiers, beam transport lines, nonlinear optics, general scheme of the laser;
- Dr. Sergey Mironov (scientific researcher), general coordination, numerical simulations of the laser pulse properties, harmonics (SH and UV) generation, harmonics (SH and UV) generation, modelling of cross-correlator operation;
- PhD student Ekaterina Gacheva, Multipass broadband Yb:KGW amplifier, delivery system of the diode pump, laser system assembling and adjustment, system of beam diagnostic;
- Victor Zelenogorsky (scientific researcher), laser pulse shaper, automation of the pulse shaping algorithm, cross-correlator for 3D shape diagnostics, spatio-temporal measurements;
- Dr. Maryana Kuzmina (scientific researcher), pulse shaper.

JINR, Dubna:

- Dr. Evgeny Syresin (group leader), beam dynamics, formation of high power electron beam in FELs, diagnostic of electron bunches in FEL;
- Dr. Sergej Kostromin (scientific researcher), developing of accelerator technique;
- Roman Makarov (engineer), development of diagnostic technique for FEL
- Dmitry Petrov (engineer), development of undulator system applied for longitudinal shape of ellipsoidal electron bunches.

2) Network/ Meetings

Please describe how the group works together. Have there been any international meetings organized by or attended by the group? What is the contribution of the group to the networking of international partners and the Helmholtz Centre?

Collaboration structure:

IAP develops new photo cathode laser system
PITZ provides opportunities to test it using existing accelerator infrastructure. Scientists at PITZ learn how to tune/operate the new system. Also technical coordination for the parallel operation of two laser systems: the existing and the upcoming (IAP developments). PITZ laser room reconstruction (T. Rublack, is responsible for these activities at PITZ) in close collaboration with IAP colleagues to fit the new system in the PITZ laser infrastructure
JINR colleagues contributing into collaboration with studies on detailed diagnostics of 3D ellipsoidal bunches including advanced method based on FEL radiation from such electron bunches.

Besides instant communication between scientists from the collaboration partners, there were several meetings involving colleagues from all sides:

- Collaboration DESY-JINR-IAP meeting on 3D ellipsoidal laser pulses in September 2013 at IAP, Nizhny Novgorod (participants: 2 experts from DESY Hamburg, 5 colleagues from DESY Zeuthen, 6 - from IAP and 1 - from JINR)
- Visit of DESY Zeuthen scientists (T. Rublack, M. Krasilnikov) to IAP in December 2014 for collaboration meeting (Introduction in general operation principles of the photo cathode laser system, tuning procedure and further discussions concerning installations at PITZ)
- 3rd German-Russian Young Researchers Forum, July, 2013, Bonn/Remagen, talk of M. Khojoyan “3D ellipsoid beams for a better performance of a high brightness photo injector”
- DESY Injector laser meeting (video conference Hamburg-Zeuthen), November, 2013, talk of M. Krasilnikov “Temporal shaping of photocathode laser pulses for photo injector optimization”
- JINR-Helmholtz meeting, E.Syresin “Developing a laser system for experimentally investigating the possibility to achieve quasi 3D ellipsoidal laser pulses”, August 2013, Dubna.

3) Scientific Progress / Milestones

How has your work plan progressed? What important milestones could be achieved during the report period? Is the progress of your work in accordance with original planning or has the work plan been changed?

Helmholtz group – DESY, Zeuthen site:

Beam dynamics simulations on application of the 3D ellipsoidal photocathode laser pulses for the PITZ photo injector optimization have been performed. To study the influence of non-perfect 3D laser shape on the electron beam quality, modelling of the 3D laser intensity distribution modifications due to imperfections in radial and longitudinal directions was done. Radial and temporal border sharpness parameters (of 3D laser shape) have been introduced into beam dynamics simulations (ASTRA) to study the influence of non-perfect 3D laser shape on the electron beam transverse emittance. Emittance has been simulated at 5.74 m downstream the cathode where the first emittance measurement station is located. Stronger impact on transverse emittance was found when having radial imperfections in 3D shape in comparison with longitudinal imperfection. The optimized transverse normalized rms emittance for 1nC bunch charge was 0.4 mm mrad assuming a perfect 3D laser distribution at the cathode. This value increases to 0.51 mm mrad (~28% growth) if 20% imperfections in radial and longitudinal directions were assumed. It should be mentioned that the best transverse

emittance at PITZ optimized for flat-top temporal laser shape is 0.6 mm mrad (simulations), that means overall 10-15 % imperfections in 3D laser shape are still acceptable in terms of transverse emittance (for comparable peak current values in both cases).
The milestone H-MS1 – Report on beam dynamics simulations for tolerances studies has been written by M. Khojoyan, the publication based on this note is under preparation.

Remarkable properties of high brightness electron source including the upgraded photocathode laser system can be used in order to produce high power photon beams, e.g. IR/THz radiation (wavelength range 5 – 100 μm). Based on the PITZ linac Terahertz light sources using synchrotron, transition and undulator radiation can provide outstanding properties. Due to its infrastructure PITZ can be considered as a proper site for the development of a THz source prototype that could be placed at the European XFEL site, allowing pump and probe experiments with X-rays and THz radiation with a time structure that is identical to that of the XFEL. Corresponding simulations have been performed by scientists of the PITZ group (P. Boonpornprasert and B. Marchetti). This includes calculations of a broad-band spectrum THz radiation based on Coherent Synchrotron Radiation (CSR) in the dipole or Coherent Transition Radiation (CTR) from a target as well as GENESIS 1.3 simulations of a narrow-band SASE FEL radiation from the APPLE-II-type undulator. The very first results of these simulations show very interesting properties of such photon sources in the peak power (up to ~100 MW for 100 μm radiation wavelength) as well as in the bandwidth of the generated radiation (2-3%). It is planned to continue these studies, in particular, by application of the 3D quasi ellipsoidal pulses to improve the quality of such IR/THz sources. There is an increasing interest to these studies in the FEL community. There is a great potential in further collaboration in this field between DESY and JINR colleagues. On the other hand the IR/THz radiation can be used for the electron beam characterization.

One of the important milestones of the overall project is a practical realization and experimental tests of the IAP developments at PITZ. The preparation for the installation of the 3D ellipsoidal laser system at PITZ is ongoing. The activities on the PITZ laser room reconstruction have been started; the general plan is completed by T. Rublack. The main goal is to provide a parallel operation of the existing and the upcoming photocathode laser systems. Up to now the planning of the reconstruction work has been successfully finished. In a first step the current laser hut and steak room have to be united. Therefore some existing walls have to be removed. Directly after the new optical tables must be inserted and installed. The next step is to build a new wall to separate the entrance area of the laser hut from the actual laser area. For all these work we have asked for quotations. The placing will be done in the next few weeks. The reconstruction works are planned for May-June of 2014.

There is a delay in tasks of the Helmholtz Association side, planned for 2 PhD students (their tasks are up to now partially covered by the existing staff). Two proper candidates have been found, the hiring procedure is ongoing, and afterwards they will be actively involved in the realization of the project goals.

IAP:

In the frame of participation at the collaborative project IAP RAS developed and created a prototype of the cathode laser with a possibility of management spatio-temporal parameters of optical pulses in the UV region. At present time, the main parts of the laser (fiber generator and amplifiers, multi-pass diode pumped disk amplifier with Yb:KGW crystals, second harmonic and UV generators, scanning cross-correlator for diagnostic of spatio-temporal parameters of optical pulses) operate properly. A shaper for spatio-temporal intensity distribution was constructively designed and installed into the laser scheme. The shaper is an optical compressor, wherein the programmable light modulators are implemented for controlling the amplitude and phase of spectral components.
The fiber part of the laser generates micro-pulses with a central wavelength of 1030 nm and

1 MHz repetition rate. These pulses are grouped to macro-pulses with the duration 300 μs, the repetition rate of macro-pulses can be varied from 1 to 10 Hz. The duration of a micropulse can be adjusted with help of optical compressor in the region 0.2-100 ps and an energy level of 0.55 μJ can be achieved. There are two optical channels at the fiber part: working and diagnostic. The pulse duration of diagnostic channel is about the Fourier Transform Limit, which is ~200 fs. The laser system provides the possibility to change the macro-pulse envelope.
The multy-pass disk amplifier with Yb:KGW crystal yields the increase of the micropulse energy up to 50 μJ. In the experiments for second and fourth harmonic generation the efficiency of energy conversion was 50% and 20%, correspondingly. The optimization of the intensity based on a chirp prism implementation resulted in an efficiency increase of up to 70%.
The cross-correlator with a scan speed of 1600 cm/sec for the detailed measurements of the spatio-temporal intensity distribution of ellipsoidal pulses from single macro-pulse with a temporal resolution of 300 fs at the time window of 50 ps was developed and realized. The nonlinear process of second harmonic generation at non-collinear interaction of working and diagnostic pulses inside the nonlinear crystal is implemented in the scheme of the cross-correlator. As far as the duration of diagnostic pulses are sufficiently shorter than the duration of working pulses the correlation function is proportional to the intensity distribution of pulses from the working channel. As a first step quasi-ellipsoidal intensity distribution of the micropulse at the fundamental frequency has been generated by the 3D pulse shaper and measured using the developed scanning cross-correlator.

JINR
JINR creates a test bench for high power laser driver applied for a FEL high average power radiation mode. High average power FEL simulations and tests applied for extreme nanolithography are being performed.

In general the progress of the work is in accordance with original planning, there is a good chance to achieve the project goals within expected schedule.

4) Financial Plan / Time Schedule

Can you comply with the financial plan and time schedule or do you see a need for adjustment?

The startup date of the project from the German side was shifted to 01.07.2014. The installation of the new photocathode laser system at the Photo Injector Test facility at DESY in Zeuthen (PITZ) is planned for the Autumn 2014. This has to be coordinated with the experimental program at PITZ, which is currently strongly involved in the preparation of the European XFEL (EXFEL) photo injector including urgent tests and run for conditioning and characterization of the main and spare RF guns for the EXFEL. This affects strongly the reconstruction works in the PITZ laser room. It was decided to shift the ordering of the equipment and consumables (planned to be covered by the project) to the second half of 2014 This corresponds to a more efficient spending of the project budget.
Besides that two PhD student positions funded in frames of the project are still opened. The selection procedure for proper candidates is finished, the hiring is ongoing.

5) Publications of the Group

A.K. Poteomkin, A.V. Andrianov, E. Gacheva, V. Zelenogorsky, S.Y. Mironov, E.A. Khazanov, M. Martyanov, E.M. Syresin, M. Krasilnikov, F. Stephan, "Generation of 3D ellipsoidal shaped UV laser pulses for the future XFEL low-emittance photo-injector", SPIE Optics+Optoelectronics, High- Power, High-Energy, and High-Intensity Laser Technology (Conference 8780A), Proceedings of SPIE Volume 8780A, 2013, 28.

M. Khojoyan, M. Krasilnikov, F. Stephan, G. Vashchenko, „Beam dynamics optimization for the high brightness PITZ photo injector using 3D ellipsoidal cathode laser pulses“in Proceedings of the 35th International Free-Electron Laser Conference, New York, NY, USA, pp.298-302.

M. Krasilnikov M. Khojoyan, F. Stephan, A. Andrianov, E. Gacheva, E. Khazanov, S. Mironov, A. Poteomkin, V. Zelenogorsky, E. Syresin, “Development of a photo cathode laser system for quasi ellipsoidal bunches at PITZ”, in Proceedings of the 35th International Free-Electron Laser Conference, New York, NY, USA, pp.303-308.

M. Krasilnikov et al., “PITZ experience on the experimental optimization of the rf photo injector for the European XFEL” in Proceedings of the 35th International Free-Electron Laser Conference, New York, NY, USA, pp.160-168.

E. Khazanov, A. Andrianov, E. Gacheva, G. Gelikonov, V. Zelenogorsky, S. Mironov, A. Poteomkin, M. Martyanov, E. Syresin, M. Krasilnikov, and F. Stephan, "Cross-Correlator for the Diagnostics of 3D Ellipsoidal Shaped UV Laser Pulses for XFEL Ultra Low-Emittance Photoinjector," in CLEO: 2013, OSA Technical Digest (online) (Optical Society of America, 2013), paper JTh2A.27

V.V. Zelenogorskii, A.V. Andrianov, E.I. Gacheva, G.V. Gelikonov, M. Krasilnikov, M.A. Mart’yanov, S.Yu. Mironov, A.K. Potemkin, E.M. Syresin, F. Stephan, E.A. Khazanov, “Scanning cross-correlator for monitoring uniform 3D ellipsoidal laser beams”, Quantum Electronics 44 (1) 76 – 82 (2014)

6) External Funding

The developments of the photocathode laser system was started in 2009 within the BMBF project (05K10CHE) “Developing a laser system for experimentally investigating the possibility to achieve quasi 3D ellipsoidal laser pulses” in the framework of the German-Russian collaboration "Development and Use of Accelerator-Based Photon Sources". Major components for first tests were ordered and assembled at IAP.
IAP (Russia) and PITZ (DESY) are providing laser and accelerator infrastructures for the advanced laser system developments and tests.
The participants form the Helmholtz Association side - PITZ staff (M. Krasilnikov, T. Rublack, M. Khojoyan) contribute part of working time to the project. As well as other experts from the Helmholtz Association side (I. Hartl and S. Schreiber from DESY Hamburg and F. Stephan and M. Gross from DESY Zeuthen) are involved in discussions and collaboration meetings.
IAP is actively using the existing infrastructure and available manpower for the project developments.
JINR implements a test bench for high power laser driver applied for a FEL high average power radiation mode. These works are funded from internal sources of the institute.

7) Patent Applications

No. of pending/granted patents

none

8) Awards received by Group Members

none