The review of the doctoral thesis
"Development of gas targets for laser-driven electron acceleration "

written by Ing. Sebastian Lorenz

Reviewer: Prof. RNDr. Pavel Kubeš, CSc.

The thesis focuses on developing gas targets for accelerating fast electrons produced by femtosecond petawatt lasers. Specifically, it addresses the flow stability and characteristics of the gas, as well as the scalability of the targets. The author presents various acceleration models and technological requirements for the targets. To describe the gas, simulations and visualized diagnostics with ultra-short pulses are utilized. The spatial distribution of the gas was determined using fluid dynamics, while the Monte-Carlo method was used to estimate gas parameters such as density, pressure, energy, and temperature.

Verification of the shape and magnitudes of plasma was made possible by the diagnostic described in the following part of the thesis. The imaging system is based on shadow, schlieren and interferometry methods, which show the deflections depending on the gradient density and the path of the diagnostic beam in the gas. To increase the sensitivity of the diagnostics, a novel 4-pass interferometry was used, and for elaboration, 3D tomographic reconstruction with the new FARM algorithm was developed.

The key condition for discerning the images is the short length of the diagnostic pulse. The method used for development and testing was CafCA compression, and the 18-fs pulse with blurring 5.4 μm enables imaging of a micro-structure in the accelerating medium.

One chapter of the doctoral thesis discusses the designed targets, including slit nozzles without and with injectors, as well as dual-stage forms. These targets should be manufactured with high precision in shape and low surface roughness.

The final section of the thesis presents the results of two campaigns performed on the ELI facility using the ultrafast optical probe as on the ALFA as on the ELBA experiments. In the ALFA experiment, electrons were accelerated up to 50 MeV with a repetition rate of 1 kHz and a pulse length of 15 fs, operating in two modes: high energy and high power. The diagnostic techniques used, including schlieren, interferometry, and spectrometry, allowed for the determination of the electron density (5.7×10^{19} m^{-3}) and the observation of a monoenergetic regime of electron beams.

The ELBA experiments produced electrons with a GeV energy level at a repetition rate of 3.3 Hz, with the capability of 100 000 shots per day. A special tower was used for beam adjustment of the target. The 27-fs pulse was focused onto a spot with dimensions of 22 μm. Diagnostic images made it possible to image the spatial, density, and energy distribution of the plasma that accelerates electrons.

The thesis contains 105 references, demonstrating its continuity with previously published research.

The author has published three papers as a first author and two papers as a co-author in reviewed journals. In addition, the author contributed to two conference proceedings and presented four oral and poster presentations, which were reported in the thesis. The author has played an important role in characterizing the gas targets, conducting tomographic reconstruction simulations, implementing diagnostics, and post-compressing optical probe pulses.

The thesis addresses the current research needs of ELI Beamlines. The gas behavior models and simulations, as well as diagnostic and target testing, were applied in experiments.

The thesis contains methods of the wider base of laser wakefield of electron acceleration, novel methods of simulation, elaboration, and interpretation of the results which were used in the final experimental research.

The thesis has successfully achieved its goals and has contributed to both theoretical and practical knowledge in the field of laser wakefield electron acceleration using petawatt power lasers.

The thesis brings scientific benefits in modeling, diagnostics, target adaptation, result elaboration and application in experiments.

The doctoral thesis is written with clear organization and logical structure, demonstrating the contribution to the accelerating MeV and GeV electrons in high-power lasers. This text aims to provide me with a deeper understanding of the problems related to plasma produced with PW lasers and to compare them with longer-living laser and discharge plasmas.

I have the following comments and question for the author to discuss:

1. Comment: The use of a four-pass setup for differential interferometry makes it possible to increase the intensity of the radiation, but it also results in a blurring of the temporal uncertainty. Question: Interferometry provides the deflection integral of the gradient density along the diagnostic path. How do you estimate the plasma density?
2. Comment: the diagnostic pulse shortening provides information on the temporal and spatial distribution of emission in shadow and schlieren pictures. In discharge and ns-laser plasmas, this diagnostic provides images of small compact structures, their magnetic fields, and filaments. Can sub-picosecond ELI plasmas be compared with anything?

Ing. Sebastian Lorenz presented novel ideas for accelerating relativistic electron beams, which were realized in experiments with international teams and published in refereed journals. I recommend to the committee accept this thesis.

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