Supervisor's review of dissertation thesis

Author: Ing. Jan Nikl
Thesis title: Modelování nelokálního transportu energie v plazmatu
Modelling of non local energy transport in laser plasma
Supervisor: doc. Ing. Milan Kuchařík, Ph.D.
Consultant: Dr. Stefan Andreas Weber

This thesis concerns the physical models and corresponding numerical methods for simulations of physical processes in laser-generated plasmas, representing an important tool for the ICF-oriented research as well as other fields of applications. The thesis focuses mainly on processes related to non-local transport of energy in the medium and the development of numerical methods for their modeling.

The thesis consists of three main parts. The first part contains a well balanced overview of the physical models describing the non-local effects in laser-produced plasma. The author starts with the full description of the kinetic theory in Chapter 1, which is reduced to the magnetohydrodynamic plasma description in Chapter 2. The simplest process of heat transport represented by the thermal conductivity model and its extension for non-local energy transfers models are reviewed in Chapter 3. Chapter 4 is dedicated to the non-local transport processes due to thermal radiation. Finally, the first part is concluded by Chapter 5, describing both geometrical and wave-based models for laser absorption processes, representing the major source of energy in the medium, implying its accurate description is crucial.

The second part of the thesis is related to the development of numerical methods and their integration into a single Lagrangian finite element (FE) framework. The basic FE formalism is reviewed in Chapter 6 and the following Chapters 7-11 describe the developed numerical models for each of the physical processes addressed in Chapters 1-5. Every Chapter is concluded by several simulations of representative examples, demonstrating validity, accuracy, convergence, and robustness of each particular numerical model.

Finally, the third part of the thesis contains the application of the developed numerical simulations codes on the realistic problems in 1D, 2D, and 3D. It contains more physically rich 1D simulations mainly related to non-local processes, including combination of hydrodynamic and kinetic approaches for one of the problems. In multiple dimensions, the simulation is more limited with respect to computational cost, so the simulations focusing on partial effects in detail are presented. These contain 2D detailed simulations of laser absorption and spontaneous magnetic field generation, and a 3D simulation of the plasma plume development.

The thesis has 181 pages and contains 220 references to literature. It is written in English with an absolute minimum of mistakes, and its structure is logical. Both the technical and scientific level of the thesis are very high. Part of the work related to the kinetic models has been performed during author's 6 months stay at the Helmholtz-Zentrum-Dresden-Rossendorf in Germany, which resulted in a joint impacted paper. Next, the work related to the raytracing laser absorption mechanism has been primarily conducted by the master student Martin Šach, with Jan Nikl serving as the advisor.

The thesis brings many new scientific results, in both the numerical and application parts. All numerical methods are well described, analyzed, their behavior is verified on well selected numerical tests, and supported by high-quality publications. Similarly, the work on the thesis resulted in a broad range of papers demonstrating ability of the developed numerical algorithms to accurately simulate realistic experiments and contribute to the interpretation of processes, which are often difficult to observe directly.

To summarize, this thesis represents an enormous amount of high-quality scientific work in complex FE numerical methods, plasma physics, and code development. Jan Nikl is capable of covering all three multi-disciplinary subjects exhaustively and conducting the scientific work independently. Another strong point is his ability to present his work in scientific papers in the top journals (such as Journal of Computational Physics or Plasma Physics and Controlled Fusion), as can be verified in his publication record. Jan Nikl has co-authored 10 papers in impacted journals (4 of them as the first author) and 11 papers in conference proceedings (6 as the first author). His doctoral thesis represents a significant contribution to the fields of FE numerical methods and applications in laser-generated plasma simulations. I warmly recommend the thesis for defense and awarding Jan Nikl the title Ph.D.

Prague, May 17, 2022
doc. Ing. Milan Kuchařík, Ph.D.