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A machine learning approach in the direct drive ICF pulse shape design

Tao Tao[1], Guannan Zheng[1], Jian Zheng[1,2]

[1] Department of Plasma Physics and Fusion Engineering and CAS Key Laboratory of Geospace Environment, University of Science and Technology of China, Hefei, Anhui 230026, People's Republic of China

[2]Collaborative Innovation Center of IFSA, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China

e-mail (speaker): tt397396@ustc.edu.cn

Pulse shaping is a powerful and easy-to-realize tool in laser fusion research. A properly formed temporal pulse could actively control the in-flight fuel adiabat and the plasma scale length, stabilizes the hazardous Rayleigh-Taylor Instability (RTI), which is a primal threat to the integrity of the fuel. A fine-tuned pulse increases the design's resilience to target defects and laser driver perturbations, without sacrificing too much compression efficiency for that purpose.

The assembling quality of implosion is highly sensitive to the fine structure of the pulse due to its non-linear character, and the configuration space of the pulse is often too large to be fully investigated. Hydrodynamics simulations on the other hand often limited by incomplete physics models and inconsistent initial conditions from real experiments, thus pulse optimization is typically an empirical procedure that significantly depends on the researcher's experience.

Here we introduce a machine learning pulse design approach[1] for the Double-Cone-Ignition[2] (DCI) scheme, it objectively evolves the pulse shapes by learning from reference implosion cases. The high areal density implosion with acceptable RTI development is the aim of the pulse shape designer. The designer is able to thoroughly scan the pulse configuration space at a reasonable computational cost by combining one-dimensional hydrodynamics simulation and linear RTI growth scaling equation. By combining correction information from high-dimensional simulations and experiment sources, the designer could incorporate non-linear instability behavior into its optimization. The designer also takes the shaping error of laser facility into account to increase its application robustness. Test runs demonstrate a steady evolution of the pulse performance, narrowing down preferable pulse parameter space for DCI, high precision two-dimensional simulation verifies the optimized pulses have the potential to increase the fuel stability while keeps the imploded areal density high (see Fig. 1).

Compared to empirical tuning procedures, the standardized and objective procedure of pulse shape optimization offers solutions with higher efficiency. The value of machine learning for laser fusion cost reduction and experiment risk management is beginning to emerge.

References

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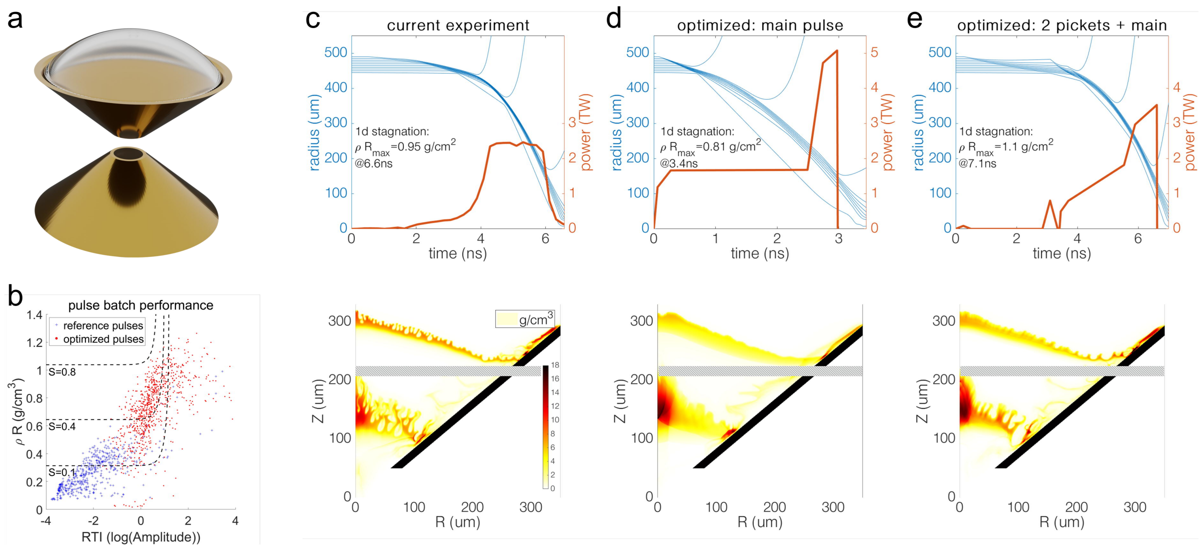

Figure 1. (a) Double-Cone-Ignition target design – the head-on placed gold cone pairs housing the ablator and fuel; (b) machine-learning pulse designer evolve pulses after learning from reference implosion cases, the optimized red batch advances in areal density and maintains the RTI at a tolerable level; (c-e) comparison between near-isentropic experiment pulse and the optimized pulses. Both the outer shell surface at acceleration and the inner shell surface at coasting are stabilized after optimization.