

Prospects for magnetic indirect drive inertial confinement fusion

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Abstract

Experimental, theoretical, simulation, and technological advances over the past 20 years are motivating a reassessment of the Magnetic Indirect Drive (MID) approach to Inertial Confinement Fusion. We outline the main physics concerns of the MID approach. These include symmetry control, minimum case-to-capsule ratio, radiation coupling into the hohlraum, and pulse-shaping of the radiation drive.

1. The magnetic indirect drive concept

The Magnetic Indirect Drive (MID) concept [1] for Inertial Confinement Fusion (ICF) marries the advantages of x-ray-driven fusion capsules, *e.g.*, higher ablation rates and illumination uniformity, with the advantages of higher energy and lower total project cost of pulsed-power drivers. In this way, the complications arising from high-intensity lasers, such as laser-plasma instabilities and hohlraum-generated x-ray M-band preheat, are avoided while retaining the possibility of using extremely high-power and high-energy drivers.

The MID concept uses a large pulsed power driver to form a plasma pinch, generating copious amounts of x-rays within a primary high-Z hohlraum that absorbs the radiation from the pinch and re-emits it with a Planckian spectrum. X-rays from the primary hohlraum are directed into a secondary hohlraum, where a uniform bath of x-rays ablates and compresses a capsule containing deuterium and tritium (DT) fuel to high temperatures, creating fusion. The capsule design utilizes a liquid layer of DT fuel suspended in a shell of low-density foam [2–4].

Experiments and simulations from 1999–2005 [1, 5–10] demonstrated many salient aspects of the MID concept using the Z accelerator, including heating the target hohlraum to a radiation temperature above 120 eV using a “static wall” hohlraum design [1]. Based in part on these early experiments, Olson *et al.* [11, 12] designed capsule and radiation systems that are

predicted to create large yields using a future, higher current, pulsed power driver. Unfortunately, further development of the MID concept was paused at that time as a result of the introduction of the National Ignition Facility (NIF) and of subsequent efforts dedicated to indirect drive capsule physics as well as a resurgence of interest in magnetic direct drive (MDD). As a result of advances in pulsed power technology and scientific computing and understanding, a reassessment of the MID concept is appropriate.

2. MID issues to be addressed

The technology and scientific knowledge available in 2005 was limited compared to the state of the art 15 years later. Improvements in pulsed power technology now make a large facility (>1000 TW) a realistic possibility. Experience at the NIF in x-ray-driven fusion concepts fostered the exploration of new designs and improvements in simulation capability and modelling that now inform our research into MID.

Many of the critical physics issues for an MID fusion platform can be evaluated with the improved simulation codes now available, but the simulation results must be benchmarked against precise experimental results to provide credible projections upon which to base future facility decisions. Experiments are proposed for both the Sandia Z machine refurbished (ZR) and NIF facilities to gain such confidence.

2.1 Hohlraum control

Uncertainty remains in our ability to model laser-driven hohlraums and to scale hohlraum behavior to larger sizes and energies. Elimination of the laser driver removes some of those concerns, but adds new ones. For example, it is expected that using a radiation-driven hohlraum will eliminate the deleterious x-ray M-band high-energy component of the capsule drive. This conjecture could be tested experimentally on the OMEGA laser facility through fielding simple experiments to establish the efficiency of coupling between the radiation entering the Radiation Entrance Hole (REH) and the capsule by measuring the time of peak compression of a symmetry capsule [13].

With laser-driven hohlraums, symmetry control is established by changing the aspect ratio of the hohlraum or by time-phasing of different cones of laser beams. For x-ray-driven hohlraums beam-phasing is not available, thus establishing the ability to control drive symmetry through changes to the hohlraum aspect ratio will have to be established. The ability to control symmetry will also affect the determination of the minimum acceptable case-to-capsule ratio (CCR) [14], the ratio of the hohlraum to capsule diameter, as the minimum CCR

is an important determining factor for the overall energy of the required driver. Experiments to establish the minimum CCR can be performed at ZR and at NIF.

The final piece of symmetry control is to determine how the radiation shine shields [17] and the effect of synchronization and power history for sources driving both open ends of a double-ended MID hohlraum affect capsule implosion symmetry. A series of experiments varying the shine shield diameter and distances from the REH and capsule are necessary to benchmark the design predictions and performance of the codes.

While radiation-hydrodynamics codes will be required to predict all of these phenomena in higher energy systems, the uncertainty in our hohlraum modelling makes establishing experimental benchmarks at any scale important.

2.2 Capsule physics

The performance and behavioral attributes of liquid layer capsule physics can only be explored at the NIF because a cryogenic capsule fuel-handling system is required. This limitation has a positive side since the experimental platforms and required diagnostics are well established at NIF [15] and would require no further development.

The most important step is to establish surrogacy, that is, the ability to predict and scale, between sub-scale (<1 MJ) and full-scale (>1.6 MJ) experiments and also between deuterium–deuterium (DD) and DT experiments. If the same knowledge can be gleaned from lower energy experiments, the stress on the laser system is reduced and more experiments can be done. If D-only fuel can be used as a surrogate, then more experiments could be conducted because competition for tritium-handling resources would be reduced. The gain from performing DD experiments is not large, as fielding these liquid layer experiments took substantially less time to execute than did ice-layer shots [16].

The next priority is to test the limits of predictions of liquid layer capsule robustness [2, 3] using the platform established by the surrogacy campaign. These predictions include the claim that lower convergence ratio (CR) implosions are less sensitive to the effects of asymmetries and do not require the same high-implosion velocities as DT ice-layer implosion designs. Additionally, the effects of engineering features such as the capsule support tent and fuel fill tube must also be compared to simulations and the mitigating effect of lower quantified CR [3].

3. Conclusions

Experiments 20 years ago demonstrated that Magnetic Indirect Drive was a possibility for ICF. To strengthen the case for MID, experiments coupled with detailed simulations must be performed at ZR and NIF to measure hohlraum dynamics, liquid layer capsule behavior, and radiation-drive management.

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