

Investigating scaling MagLIF to higher current loads with Chimera

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Abstract

Magnetized Liner Inertial Fusion is a magneto-inertial fusion scheme being pursued on the Z machine at SNL, where a current run axially up a liner compresses fusion fuel via the Lorentz force. The maximum load current is at present 20 MA, however there is interest in how MagLIF will scale to higher currents. Work by Ruiz et al. at SNL derived scaling laws for the parameters of MagLIF experiments to predict the performance at higher currents [2], finding them to agree well with results from 2D HYDRA simulations [4]. In this work, 1D simulations were conducted using the MHD code Chimera [3], to investigate these scaling laws. Good agreement was found on some metrics (e.g. T_{ion}), while discrepancies were seen with others (e.g. burn width). It was found that increased shock resolution led to improved performance in higher resolution Chimera simulations. Chimera simulations were further used to investigate the effect of the axial B_z field on plasma conditions and α -particle trapping, where it was found that the application of the field improved α -trapping.

Introduction

In [2] and [4] Ruiz et al. derived laws to scale MagLIF to currents of up to 60 MA, while maintaining a rise time of ≈ 125 ns. HYDRA simulations set-up according to these laws verified the analytical scaling expectations. One such result can be seen in Fig. (1).

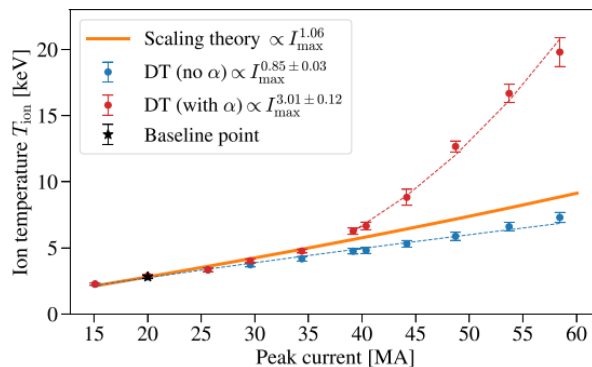


Figure 1: Burn-averaged T_i against I_{max} for HYDRA simulations, and its scaling law [4].

These same laws were used to set-up simulations in the MHD code Chimera, developed by

Imperial College London, and the scaling of various simulation metrics with peak load current was assessed as an independent assessment of these laws.

The Chimera simulations were run in 1D and modelled the load current with current-time pairs, while HYDRA used 2D and a circuit model. Only α -particle-off simulations were used for comparison between HYDRA and Chimera.

Chimera simulation mesh resolution

In the course of this work it was found that the results of Chimera MagLIF simulations are dependent on simulation mesh resolution, in particular fusion yield and ion temperature (T_i) were found to increase as cell-size decreased. Simulations were run across a span of cell-sizes from $5\mu\text{m}$ to $1\mu\text{m}$ and showed no signs of converging. As shown in Fig. (2a), the scaling of performance with resolution decreases as peak load current increased.

Fig. (1b) indicates that this may be due to increased shock resolution. Cell velocity was analysed for the $115 - 120\mu\text{m}$ region (fuel-liner interface at ≈ 119 ns) for the $1\mu\text{m}$ and $5\mu\text{m}$ simulations. As can be seen in Fig. (1b), the variations in cell velocity is significantly smoother for the $5\mu\text{m}$ simulation, indicating that the $1\mu\text{m}$ is resolving shocks in greater detail. At ≈ 119 ns the difference in shock resolutions is particularly pronounced, this also corresponds to a much higher T_i for the $1\mu\text{m}$ simulation.

It therefore appears that decreasing the cell size in Chimera leads to higher shock resolution, which drives the improved performance seen in these higher mesh resolution simulations.

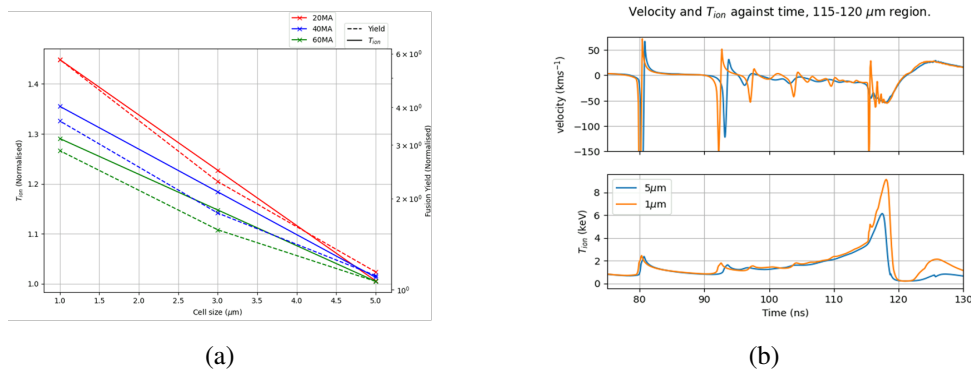


Figure 2: (a): T_i and fusion yield against cell-size of Chimera simulations. (b): cell velocity and T_i against time for the $115 - 120\mu\text{m}$ region for Chimera simulations.

Metric comparisons

Chimera simulations were set-up according to the Ruiz scaling laws for peak load currents of 20, 40, and 60 MA. Good agreement between Chimera, HYDRA, and the scaling laws were

found for the majority of metrics, such as T_i , fusion yield, and plasma pressure. However, for some metrics there was worse agreement, such as burn width and convergence ratio.

The liner defects present in 2D HYDRA simulations were not represented in the 1D Chimera simulations, these perturbations can result in uneven and premature burn, leading to shorter burn width and reduced compression. These perturbations are likely responsible for the inconsistencies. Other causes of the discrepancies could be differences between the codes, such as the load current modelling.

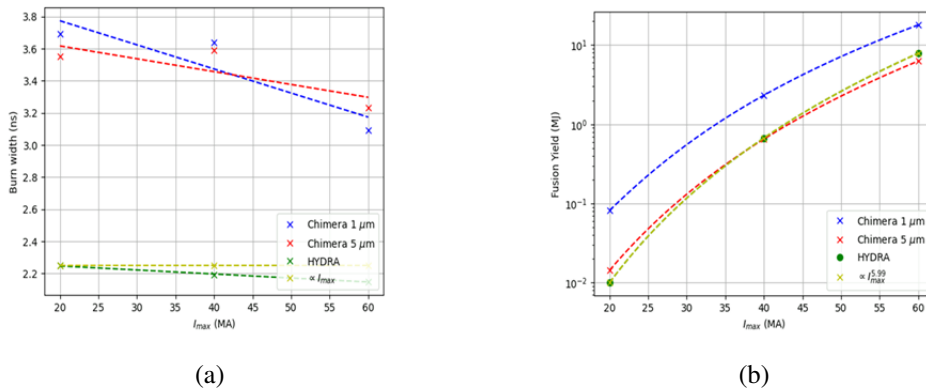


Figure 3: Plots showing how burn width (a) and fusion yield (b) scale with peak load current for Chimera, HYDRA, and the Ruiz scaling laws [4].

$B_z \propto$ particle trapping

The primary purpose of the B_z field is to limit thermal conduction to the liner walls. However, it is also expected to assist in the trapping of α particles in the fuel.

60 MA Chimera simulations with MC α -transport were run for a range of B_z strengths, and the α mean-free-paths (λ) were compared to assess the α trapping. The radial λ (λ_r) is the λ in only the radial direction, while λ_{3D} is the λ accounting for α movement in all three directions.

The radial λ decreased linearly as the B_z field strength increases, indicating α trapping. Evidence of increased α trapping towards the fuel centre can also be seen in the streak plots.

Applying a B_z glues α 's to the field lines, with the α 's precessing around them. Increasing the strength at low B_z provides a strong decrease in Larmor radius (r_L) and a strong increase in ω_L , increasing the λ_{3D} . As the B_z increases further the decrease in r_L , and therefore the increase in ω_L and λ_z diminishes, but λ_r continues to drop linearly. This results in a drop in overall λ_{3D} .

Conclusions and Further work

The no- α Chimera simulations were able to replicate the HYDRA simulations to a good standard, providing confidence in the resilience of MagLIF as it is driven with higher loads. In-

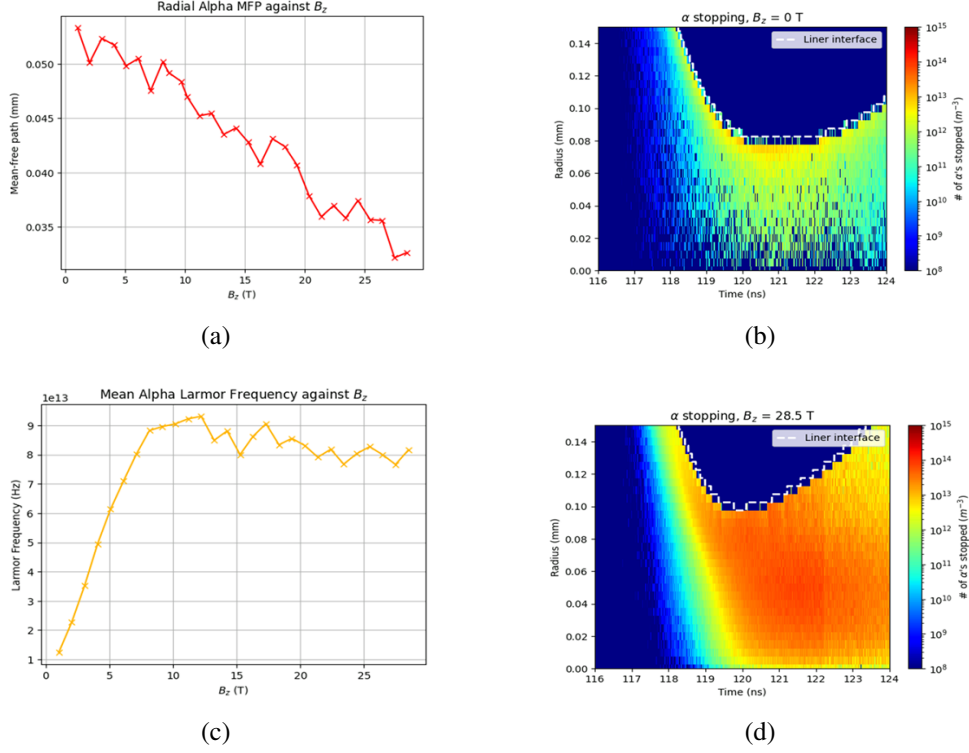


Figure 4: (a) and (c) show how λ_α and ω_L scale with applied B_z . (b) and (d) are streak plots showing greater α stopping towards the fuel centre in the presence of an applied B_z .

consistencies were likely due to differences in 1D and 2D simulations. Imperial are developing an α -diffusion model which can be tested against the α -on HYDRA simulations to expand on this work. These simulations can be extended to 2D to incorporate the effect of liner perturbations and MRTI growth. This will also allow for further extensions of MagLIF, for example using a composite liner.

Increasing Chimera mesh resolution led to an increase in simulation performance, possibly due to better resolving shocks. This can be better examined by using more compute power or simpler simulations to simulate smaller cell-sizes in search of a mesh convergence.

A study of how the axial B_z field affects the λ_α indicates that the B_z is effective at trapping the α 's by more tightly gluing them to the field lines, decreasing their λ_r .

References

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