Controlling the symmetry of direct-drive implosions with target shimming

Fredrick H. Séguin et al., MIT

APS 2005
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Summary

1) Target shimming changes nuclear burn symmetry

2) Drive asymmetry results in burn asymmetry and reduced performance

3) Shimming could counteract drive asymmetry
   - Polar Direct Drive
   - Indirect Drive

4) A formula is proposed for estimating the amount of shimming necessary
# Collaborators

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Lawrence Livermore National Laboratory

K. Mikaelian
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R. Tipton
Other Colleagues doing related work

Neutron imaging of DT burn at OMEGA

- L. Disdier et al.
- C. Christensen, G. Grim et al.

Study of $P_4$ shimming in indirect drive at the Sandia Z pinch

- D. Callahan, G. Bennet et al.
Two types of target were illuminated symmetrically by 22-kJ, 1-ns square laser pulses at OMEGA.

1 Spherical target

- CH
- 18 atm D\textsuperscript{3}He
- \( \tau = 18.3 \mu m \)

2 Shimmed targets

- \( \theta \)
- 19.1 \mu m
- 21 \mu m

\[
\tau(\theta) = \sum_{\ell} A_{\ell} P_{\ell}(\cos \theta)
\]

is dominated by \( P_0 \) and \( P_2 \),

\[
A_2 / A_0 = 0.07
\]
Orthogonal proton emission imaging cameras were used to study the spatial distribution of nuclear burn

Séguin et al., RSI 74, p. 975
DeCiantis et al, RSI, accepted
DeCiantis et al, PoP, submitted
Séguin et al., PoP, to be subm.
The spherical target imploded symmetrically

**Shot 40534**

- $R_{\text{xray}} = 38 \pm 5 \ \mu m$
- $R_{\text{burn}} = 31 \pm 2 \ \mu m$

**D$^3$He reactions**

- $400 \ \mu m$
- $R_{\text{burn}} = 29 \pm 2 \ \mu m$

**Surface brightness**

- 0 to 50 $\mu m$
The shimmed targets imploded with prolate asymmetry

Each image is now characterized by two different radii (for the long and short axes), as plotted on the next page.
Burn measurements and x-ray measurements show similar distortion in core and shell due to shimming.

\[
R_{\text{long}} / R_{\text{short}} \approx 2.1
\]

\[
A_2 / A_0 \approx 0.55
\]

for the shimmed target.
Asymmetric drive leads to asymmetric burn and reduced yield
There are systematic connections between burn asymmetry and each of its causes.

From data, we might speculate that
\[ \frac{\delta \tau}{\langle \tau \rangle} \sim \frac{1}{2} \frac{\delta I}{\langle I \rangle} \]
will cancel asymmetry.
Let’s vary the shell thickness to get uniform implosion velocity and radius after the acceleration phase.

Fuel-shell interface after acceleration phase:
- Uniform radial velocity
- Nearly spherical

After coasting phase

At bang time
The shell thickness variation required to keep the implosion velocity symmetric can be estimated from the ablation-driven rocket equations:

For direct drive (from J.D. Lindl, PoP 2, p. 3933):

\[ \dot{m} = \alpha I^{1/3}; \quad v_{imp} = \beta I^{1/3} \ln \left( \frac{m_0}{m} \right) \]

To lowest order, the angular thickness distribution that gives uniform implosion velocity after acceleration is:

\[ \frac{\delta \tau(\theta)}{\langle \tau \rangle} \approx \frac{2}{3} \left[ 1 - \frac{1}{4} \frac{\langle d \tau \rangle_{ablation}}{\langle \tau \rangle} \right] \frac{\delta I(\theta)}{\langle I \rangle} \]
We can estimate what this means for typical OMEGA shots

\[ 22 \text{ kJ} \Rightarrow \langle d\tau \rangle_{\text{ablation}} \approx 10 - 12 \mu\text{m} \Rightarrow \]

\[
\frac{\delta \tau(\theta)}{\langle \tau \rangle} \approx \frac{2}{3} \left[ 1 - \frac{3 \mu\text{m}}{\langle \tau \rangle} \right] \frac{\delta I(\theta)}{\langle I \rangle}
\]

\[ \langle \tau \rangle = 20 \mu\text{m} \Rightarrow \]

\[
\frac{\delta \tau(\theta)}{\langle \tau \rangle} \approx 0.6 \frac{\delta I(\theta)}{\langle I \rangle}
\]

From data, we speculated

\[
\frac{\delta \tau}{\langle \tau \rangle} \sim \frac{1}{2} \frac{\delta I}{\langle I \rangle}
\]

The shell thickness variation required to counterbalance a 10% intensity variation is

\[ \delta \tau \approx 1.2 \mu\text{m} \]
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