SAND2017-8544C

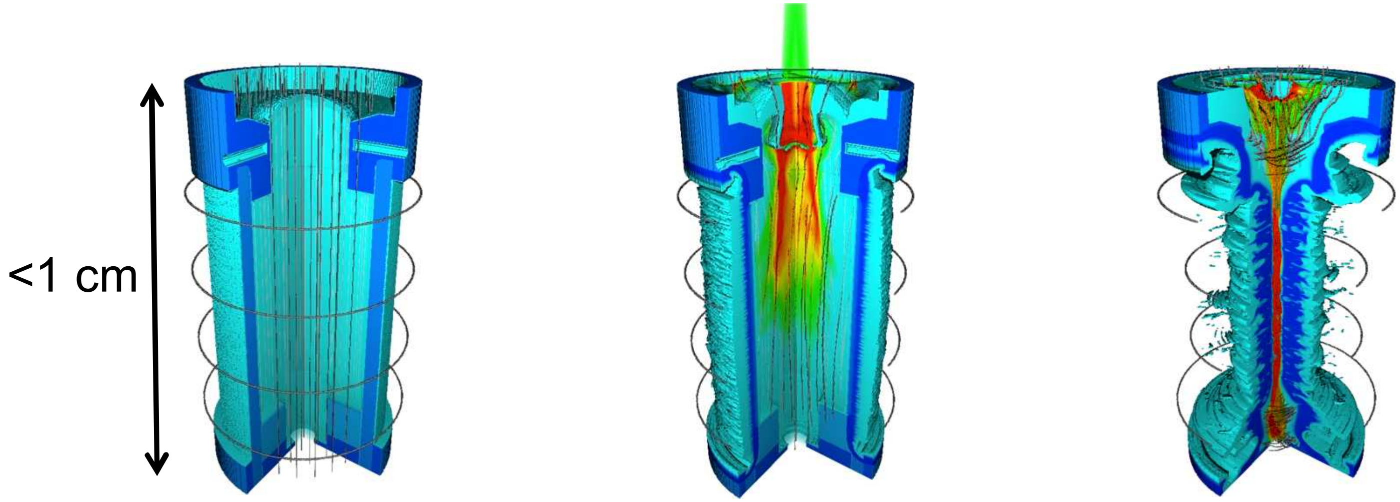
Recent Results of the MagLIF Peak Load Current Diagnostic

M. H. Hess, K. J. Peterson, D. J. Ampleford, B. T. Hutsel,
C. A. Jennings, D. H. Dolan, W. A. Stygar, M. R. Gomez,
M. R. Martin, G. K. Robertson, and D. B. Sinars

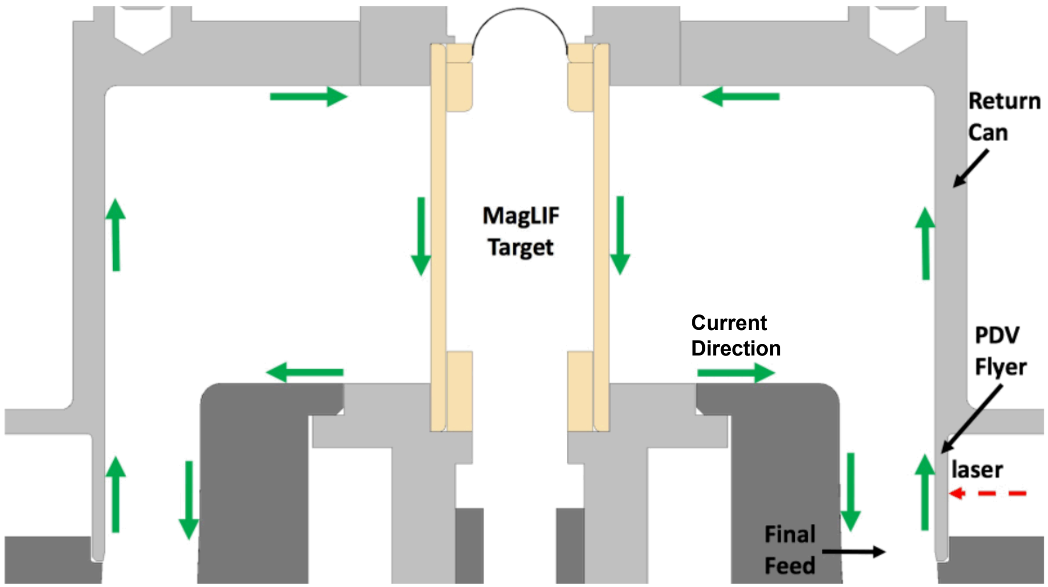
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Motivation

- A novel fusion concept called MagLIF[1] (Magnetized Liner Inertial Fusion) is currently under development at Sandia.
  - A cylindrical metal liner, e.g. Al or Be, that contains a fuel is initially axially magnetized.
  - The fuel is preheated with a laser.
  - The liner, fuel, and magnetic field are all compressed with a high-current magnetic drive, e.g. Z machine, which can lead to fusion relevant conditions in the fuel.
  - The compressed axial magnetic field gives reduced electron thermal heat conduction losses and increased ion confinement.



PDV/VISAR Load Current Diagnostic



- Our PDV/VISAR system uses laser interferometry to measure the velocity of the metal flyer which is a few millimeters below the return can in the final power feed.
- The flyer velocity is due to the magnetic pressure from the MagLIF load current.
- Using an MHD code such as, ALEGRA[2], one can perform forward calculations to unfold the approximate time-dependent load current, which yields the measured flyer velocity.

Peak Load Current Diagnostic

- Although measuring the entire time-dependent load current is desirable, the unfold process can be time consuming, i.e. it requires hundreds or even thousands of simulations. Moreover, it is difficult to assess the uncertainty associated with the unfold since it is an ill-posed problem, i.e. different currents may produce very similar flyer velocities.

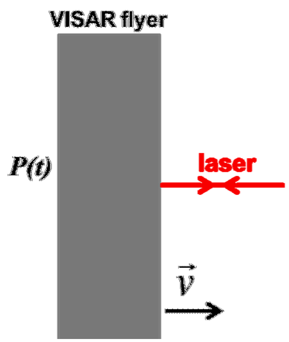
- However, for MagLIF loads, it is possible to perform a quick (< 1 hour) and accurate (< %5 uncertainty) analysis of the PDV/VISAR diagnostic to measure the peak load current.

- This measurement is relatively insensitive to the shape of the load current, which implies that we do not need to go through a time consuming process as was done in full current unfolds.

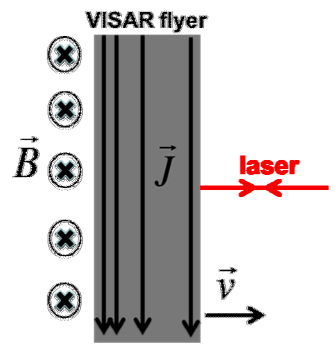
- This measurement allows us to inform upcoming experiments in a timely fashion about the peak load current delivered on a previous shot.

Increasing the Flyer Thickness

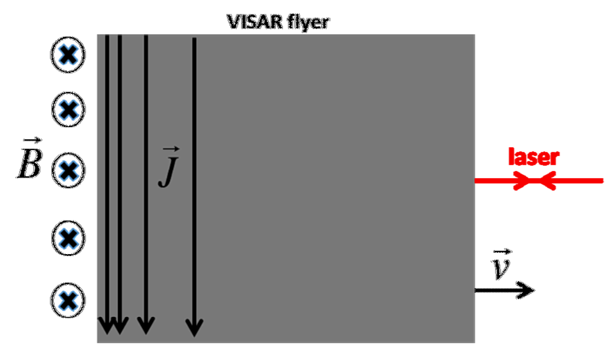
- Previous work on mechanical pressure driven VISAR[3] showed that the magnitude of the flyer velocity at some time depended on the pressure at an earlier time on the opposite surface, but did not explicitly depend on the flyer thickness. Therefore, the magnitude of a local velocity maxima only depends on the local maximum pressure applied at an earlier time.
- In general, magnetic pressure PDV/VISAR has nonlinear distributed JxB forces, so the flyer velocity magnitude will depend on the thickness. By increasing the flyer thickness however, the JxB forces are “more localized” to the flyer surface and take longer to diffuse. The system then resembles a mechanical pressure driven PDV/VISAR.
- For a 120 ns MagLIF load current, a 600 μm thick flyer is sufficiently thick to reduce the effect of the distributed JxB forces.



Mechanical Pressure PDV/VISAR



Magnetic Pressure PDV/VISAR



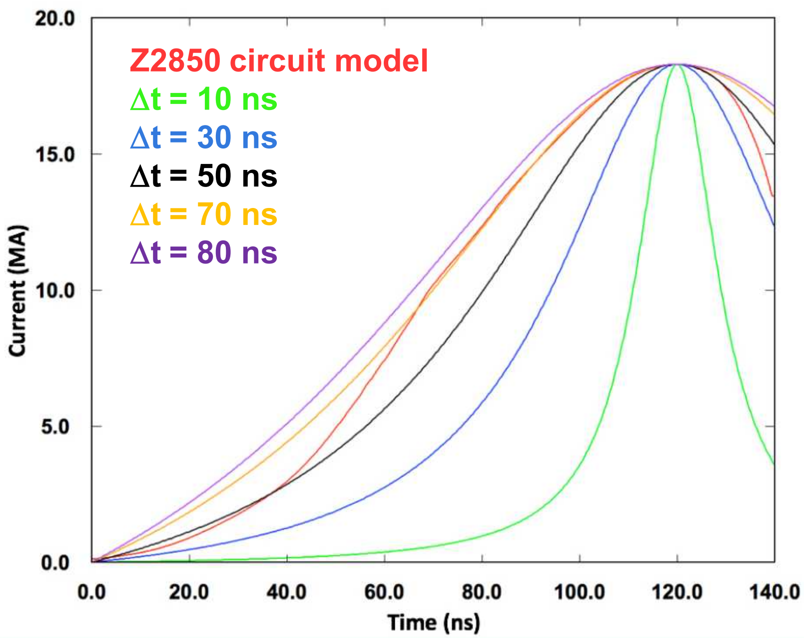
Larger Thickness PDV/VISAR

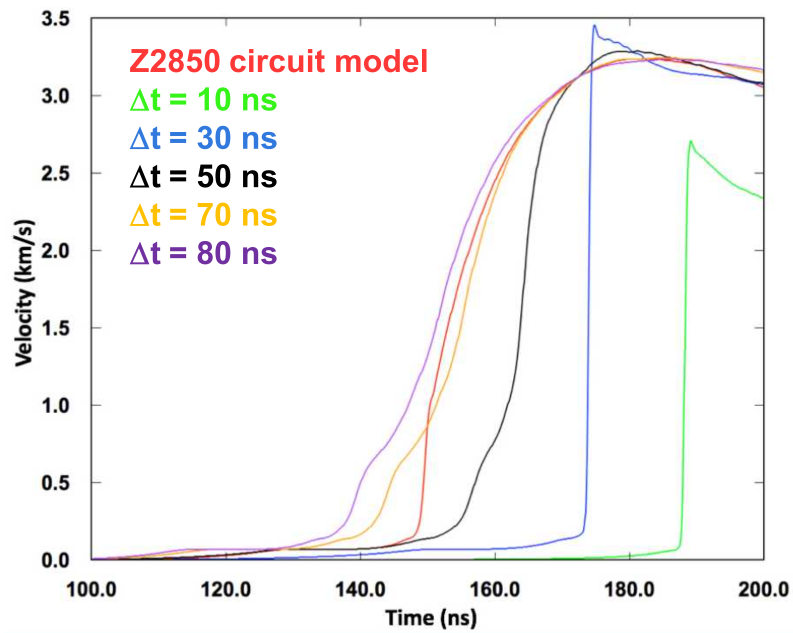
Peak Current and Peak Velocity

- MagLIF current profiles are typically ~120 ns in length, monotonically increase to a peak current, and then have an inductive dip.

- We compare the simulated flyer velocity using a MagLIF circuit model load current with Lorentzian shaped current pulses that have the same peak load current (18.3 MA) at the same peak time of 120 ns.

$$I(t) = \frac{I_{peak}}{1 - f(t_{peak})}\left(f(t - t_{peak}) - f(t_{peak})\right) \qquad f(t) = \frac{1}{1 + t^2/\Delta t^2}$$





Comparing Peak Velocities

- We find that wider current peaks produce less variation in the peak velocity because
  - wider current peaks cause less shocking of the flyer
  - wider current peaks delay the time of the pressure release wave to erode the pressure peak

- The MagLIF circuit model produces load currents with shapes bounded by the Lorentzian model of 50 ns < Δt < 70 ns.

- From the table below, we expect that differences in shape would cause a 1.6% variation in the peak flyer velocity.

	Current Model	Peak Velocity (km/s)
	Z2850 Circuit	3.236
Outside of MagLIF range	$\Delta t = 10$ ns	2.710
	$\Delta t = 30$ ns	3.456
Within MagLIF range	$\Delta t = 50$ ns	3.286
	$\Delta t = 70$ ns	3.242
	$\Delta t = 80$ ns	3.234

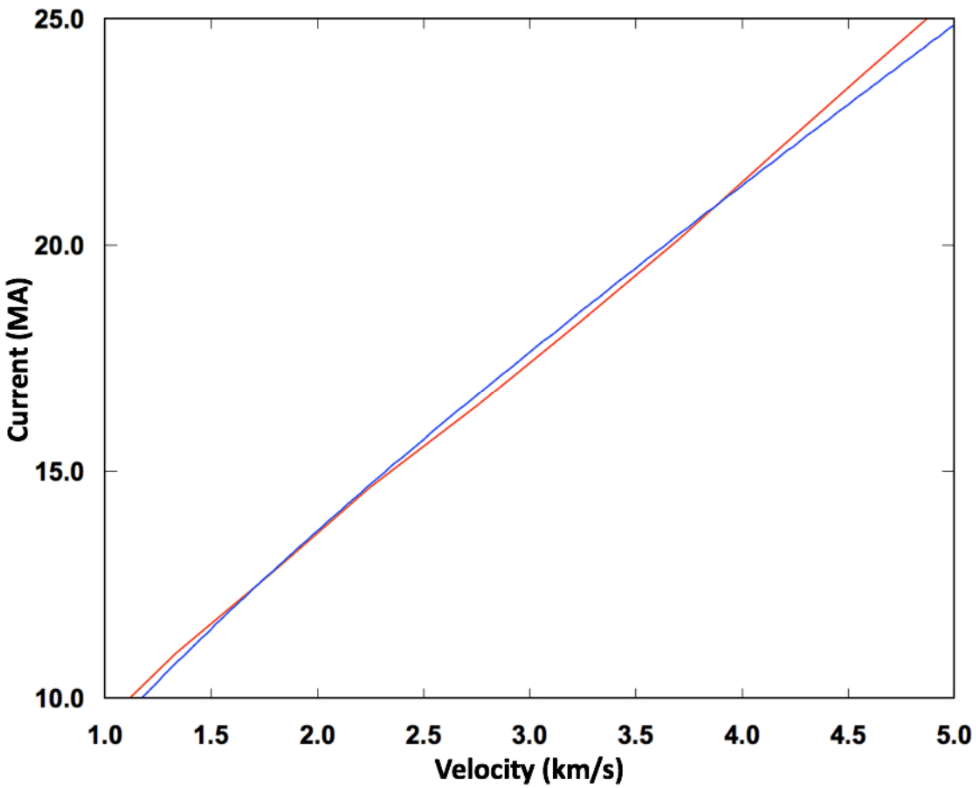
Inferring the Peak Current from the Peak Flyer Velocity

- By performing a series of forward simulations with ALEGRA, we can produce a curve (red) which relates the peak load current and peak velocity for a 600 μm aluminum flyer at a radius of 1.3 cm.

- The blue curve shows a 1-D model of the flyer velocity using the following peak mechanical pressure/peak velocity formula from Ref. 3 and the T = 298 K Al 3700 SESAME[4] table.

$$v = 2 \int_0^P \frac{dP}{\rho(P) c(P)}$$

- The blue curve demonstrates the similarity of the larger thickness PDV/VISAR concept to the mechanical driven concept. It can also be used to estimate the uncertainty of the inferred peak load current for a given EOS uncertainty.



Effect of EOS Uncertainty

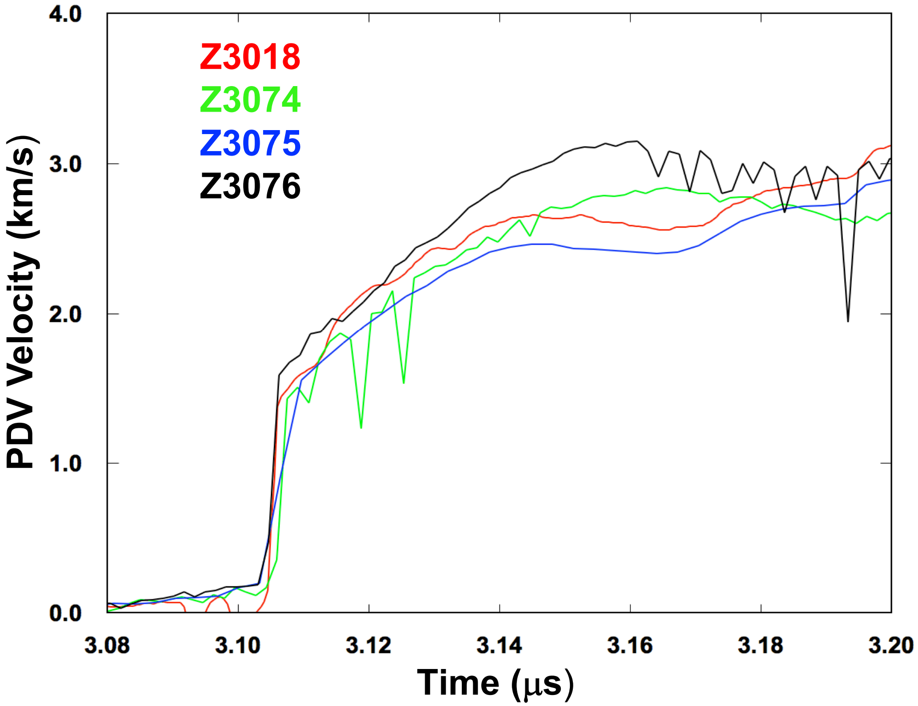
- Suppose that we apply a uniform uncertainty to the SESAME EOS pressure function:

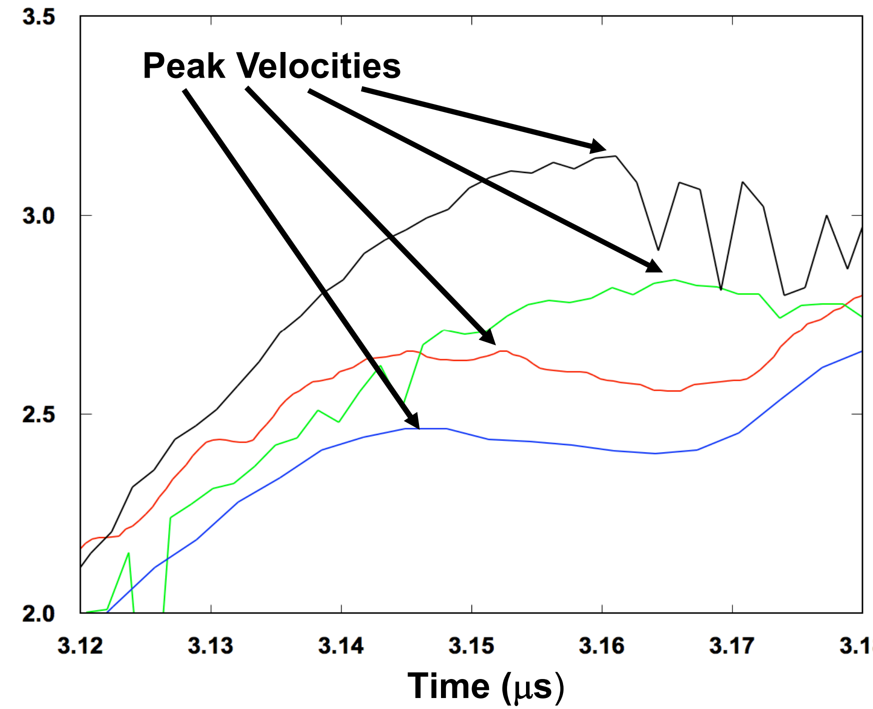
$$P(\rho) = (1 + \delta) P_{true}(\rho)$$

- The uncertainty causes a shift in the peak velocity vs. peak pressure curve, and hence, a shift in the peak velocity vs. peak current curve.
- This allows us to estimate the uncertainty in our inferred peak current due to a uniform uncertainty in the EOS.
- The following table shows the fractional uncertainty in the inferred peak current, $\delta I / I$, for a measured peak velocity v:

	δ = 5%	δ = 10%	δ =20%
v = 2 km/s	0.94%	1.9%	3.7%
v = 3 km/s	0.85%	1.7%	3.4%
v = 4 km/s	0.84%	1.6%	3.1%
v = 5 km/s	0.68%	1.4%	2.7%

MagLIF PDV Data





Z3018: AR 9, OR = 2.616 mm (Be), v_{peak} = 2.638 +/- 0.015 km/s

Z3074: AR 11, OR = 3.400 mm (Be) + 70 μm coating, v_{peak} = 2.822 +/- 0.014 km/s

Z3075: AR 9, OR = 2.567 mm (Be) + 75 μm coating, v_{peak} = 2.435 +/- 0.015 km/s

Z3076: AR 11, OR = 3.400 mm (Be) + 70 μm coating, v_{peak} = 3.080 +/- 0.098 km/s

Uncertainty Estimate in Peak Load Current

- We present a total peak load current fractional uncertainty estimate based on the following uncertainties:
  - uncertainty in measured peak velocity
  - uncertainty in current pulse shape
  - uncertainty in equation of state

Shot	Frac. Uncer. in v_{peak}	Frac. Uncer. Current Shape	Frac. Uncer. w/ %5 EOS Uncertainty	Frac. Uncer. w/ %10 EOS Uncer.	Total Uncer. w/ 5% EOS Uncer.	Total Uncer. w/ 10% EOS Uncer.
3018	0.57%	1.6%	0.88%	1.77%	1.9%	2.5%
3074	0.50%	1.6%	0.87%	1.74%	1.9%	2.4%
3075	0.62%	1.6%	0.90%	1.81%	1.9%	2.5%
3076	3.0%	1.6%	0.85%	1.69%	3.5%	3.8%

Diagnostic Comparison to BERTHA Circuit Model[5]

Sandia National Laboratories

- A circuit model of the entire Z machine has been developed using BERTHA which can be used for preshot prediction and post shot analysis.
- The circuit model has been tuned over many different types of loads including MagLIF.
- At present, we estimate the uncertainty in the peak current from the circuit model to be approximately 5%.

Shot	PDV Diagnostic (MA) (5% / 10% EOS Uncer.)	BERTHA Circuit (MA)
3018	16.0 +/- (0.3 / 0.4)	15.2 +/- 0.8
3074	16.7 +/- (0.3 / 0.4)	17.9 +/- 0.9
3075	15.2 +/- (0.3 / 0.4)	15.2 +/- 0.8
3076	17.7 +/- (0.6 / 0.7)	18.5 +/- 0.9

Summary/Future Work

- We have developed a novel PDV/VISAR diagnostic which provides a quick and accurate measurement of the MagLIF peak load current.
- We have estimated the uncertainty in the peak load current measurement based on uncertainties from: measured peak flyer velocity, the flyer equation of state, and current pulse shape.
- We are currently working on an estimate of the peak load current uncertainty due to the uncertainty in the flyer conductivity model.
- At present, we find good agreement between the peak load current measurement obtained from this diagnostic and the predicted peak load current of a Z machine circuit model developed at Sandia.

References

[1]S. A. Slutz, M. C. Herrmann, R. A. Vesey, A. B. Sefkow, D.B. Sinars, D. C. Rovang, K. J. Peterson, and M. E. Cuneo, Phys. Plasmas 17, 056303, 2010.

[2]A. C. Robinson, et. al., AIAA Aerospace Sciences Meeting, January 2008, AIAA2008-1235.

[3]M. Hess, K. Peterson, and A. Harvey-Thompson, High Power Laser Science and Engineering 3, e22 doi:10.1017/hpl.2015.23 2015.

[4]K. S. Holian, Los Alamos Lab. Rpt. LA-10160-MS. 1984.

[5]B. T. Hutsel et. al., To be submitted 2017.