LA-UR- 97-2809

CONF-9705120--2

EXAMINATION OF INSTABILITY GROWTH IN SOLID LINER SURFACES USING COMPARISONS OF TWO DIMENSIONAL MHD CALCULATIONS AND MEASURED DATA

RECEIVED
AUG 13 1997
OSTI

W.L. Atchison, R.J. Faehl, Dane V. Morgan, and R. E. Reinovsky

Plasma Applications Group, Hydrodynamics and Xray Physics Group,
And Pulsed Power Program Office,
Los Alamos National Laboratory, Los Alamos New Mexico 87545.

Experiments being conducted at the Los Alamos National Laboratory Pegasus facility are examining stability issues for driving an aluminum liner with a pulsed magnetic field. The Pegasus facility provides a current of 5 to 8 Megamperes to compress a cylindrical liner. Liners of various size and thickness are used, depending on the specific experimental objectives. In several of these experiments, the outer surface clearly develops perturbations in the mass distribution. These perturbations are strongest when the aluminum is suspected to have melted and in some cases partially vaporized. A series of specific experiments was designed to examine the growth rate of these instabilities. These experiments involved machining a sine wave onto the outer surface of the liner to seed a given wavelength. Two-dimensional MHD calculations, using the measured current profile, were performed to model the behavior of the liner under magnetic field compression. These predictions were made with a 2D Eulerian code complete with a Steinberg-Guinan strength model. The results of these calculations will be discussed in this paper. The density contours at specific times will be compared with the processed radiography.

The utility of a liner as a hydrodynamic driver requires maintaining integrity while accelerating it to sufficient velocities. The Liner Stability experiments at the Los Alamos National Laboratory Pegasus facility examine stability issues for cylindrical liners driven by magnetic fields. This paper will address several experiments that examine the growth of pre-seeded single wavelength modes. These perturbations were machined in a standard liner design used by the Pegasus facility. Radiographic data and 2D numerical simulations show close agreement in the amplitude growth and shape of these structures. Close examination of the results from the numerical simulations suggests

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

a stronger dependence on magnetic field effects in the growth than has been claimed in the past.

Past analyses (e.g. 1,2) have treated the growth of such instabilities using linear first order perturbation theory. The conclusion reached has been that these instabilities are identical to Rayleigh-Taylor instabilities. The analysis is based on linearization of the fluid and the magnetic diffusion equations neglecting second order terms. Several studies (3,4,5) modified this treatment to include the effects of strength and plasticity to describe solid liners in plastic flow. These enhancements were used to calculate growth thresholds, which depend on initial amplitude and wavelength, as well as growth rates. Any effects that might be attributable to perturbations in the local field were not treated. Swegle and Robinson (6,7) broke from identifying this instability with classic Rayleigh-Taylor, but only so far as attributing the growth to a non-isotropic part of the stress tensor. In the calculations conducted for this effort we observed that these spatial varying elements of the stress deviator appear to be derived from the contributions of magnetic field perturbations acting on the spatially varying part of the current density. We also observed that this trend is enhanced by the temperature dependence of the conductivity as it affects the diffusion of these field and current perturbations.

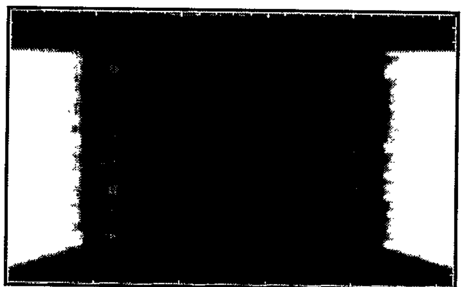


Figure 1. Radiogram from Megabar-1

Plasma z-pinches, used as soft x-ray sources, characteristically develop severe instabilities at late time. In experiments and 2D modeling (8,9) of these instabilities, the material tends to aggregate into longer wavelength structures instead of random or short wavelength features. In solid liner experiments where the outside surface melts, instabilities are often observed to develop on the surface. Figure 1 exemplifies a radiogram with these instabilities present. Fourier analysis performed on the structures in this image shows the largest amplitudes lie in the wavelength region between 1 to 2 mm with a soft cut off at approximately 250 to 350 micron. The size and resolution of the radiograms limit the useful spectral region to between 100 micron and 2 cm, but the data is sufficient to show that mode amplitude decreases as wavelength decreases from 1 mm to 200 micron. This trend for longer wavelengths to dominate is consistent with most experiments conducted to date. While the strength and plasticity can be used to explain the stabilization of short wavelengths in solids, calculations indicate the surface of the liner in Figure 1 is melted and there is no strength in the plasma pinches used for the soft x-ray experiments. This would appear to contradict classic Rayleigh-Taylor instability analysis for this early stage

This apparent contradiction led to the design of three liner stability experiments using sinusoidal perturbations of varying amplitude and wavelength machined on the outside of the liners. The basic liner was a cylinder 2.0 cm long, 400 ~ 430 micron thick, 2.4 cm in radius, and was fabricated of soft aluminum (1100-O). Each half along the zaxis had a different machined surface. Table 1 summarizes the three liners actually used. These liners were then driven in a z-pinch with currents in the 4-6 MA range. Several diagnostics including radiography, field and current measurements, and contact pin measurements were used to measure conditions of the liner at various times.

Table 1. Liner Stability Experiments 4 through 6

Liner Configuration	Side 1		Side 2		Peak Current
	Amplitude	Wavelength	Amplitude	Wavelength	
LS - 4	Smooth	None	50.0 μ	2.00 mm	4.6 MA
LS - 5	25.0 μ	2.0 mm	25.0 μ	0.75 mm	6.3 MA
LS - 6	12.5 μ	2.0 mm	12.5 μ	0.50 mm	6.3 MA

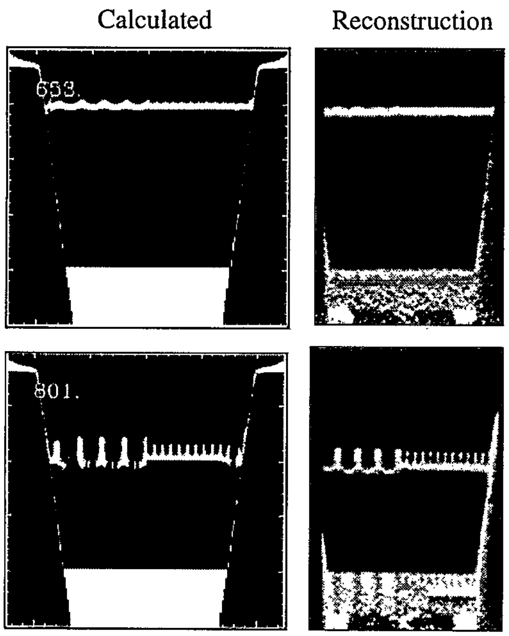
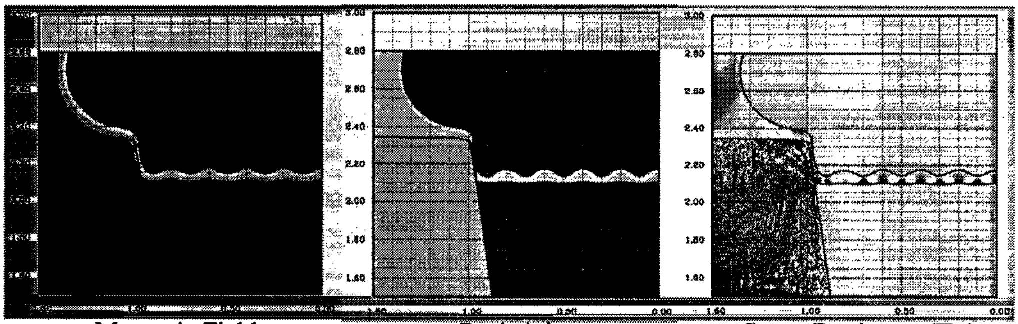


Figure 2. Calculated vs. reconstruction at 6.5 (top) and 8.0 (bottom) μsec

A series of side looking X-ray shadowgraphs were obtained using pulsed X-ray sources. These radiograms were processed with common image processing techniques to minimize the impact of noise. The images were then processed using an approximate, discrete Abel inversion technique to produce attenuation factor contours in r and z. This process assumed an average linear attenuation coefficient with no spectral dependence on thickness of the absorber, no x-ray scatter, and azimuthal symmetry. While the resulting contours are relatively imprecise, the results are sufficient to reconstruct the cross-sectional shape of the liner based on the radiograms. In this manner, details of both the outer and inner surface can be compared to 2D calculations

Numerical predictions were provided by a 2D Eulerian code using SESAME tabular equations of state. The algorithm uses a Steinberg-Guinan strength model with a Lindeman melt model. Figure 2 shows the level of agreement was very good between the calculated shape and the shape reconstructed from the radiograms. The two times shown are examples of linear and non-linear stages. In the linear stage the shape of the perturbations are still sinusoidal. The non-linear stage clearly shows the spike and bubble phase commonly seen just before the liner ruptures.

The mechanism that causes the growth of these structures in the 2D calculations appears to be non-isotropic shear stresses in part caused by the spatial distribution of magnetic fields, currents, and conductivity. This is inferred from the fact that the spatially



Magnetic Field Resistivity Stress Deviatory (T_{zz})

Figure 3. Spatial variations under perturbation

varying part of these quantities appears to follow the form of the initial perturbations at early times even before plastic flow begins. Figure 3 shows the spatial variations these parameters exhibit. While these spatial variations are initially small, as the field grows and diffuses into the material their magnitudes grow until they are no longer negligible. There also appears to be an enhancement that results from the temperature dependence of the electrical conductivity. The slightly higher current density in the valleys resulting from the shape of the surface perturbation and decreased cross-sectional area causes the resistivity to be infinitesimally higher. The decreased resistivity in the valley allows for a slight modification of the field diffusion. This degenerative process eventually results in the field and conductivity distributions shown in Figure 3.

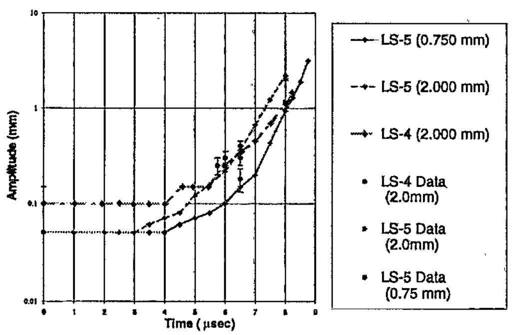


Figure 4. Perturbation Growth

Figure 4 shows the close agreement between predicted and measured amplitudes and suggests the explanation of structure growth derived from the calculations may be correct. However, this analysis falls short of verifying that the relationship between field diffusion, ohmic heating, plastic deformation, and instability growth is the dominant factor; but several observations can be made. Growth of the perturbation is resisted until the stress exceeds yield strength. During plastic flow, growth begins slowly but the rate increases, eventually yielding to nearly exponential growth. Short wavelength perturbations are suppressed longer. Unfortunately, in all the cases in this study, the liner goes into the bubble and spike phase very quickly and rate comparisons are difficult and possibly unreliable at later times. The spatial variations shown in Figure 3 form well before the material yields. This suggests the mechanism for redistributing the material within the liner exist even before flow starts. Future plans include using the 2D models to examine the relative magnitude of "higher order" terms compared to linearized theory with a hope of using selected terms to explore analytic techniques.

1. Harris, E. G., "Rayleigh-Taylor Instabilities of a Collapsing Cylindrical Shell in a Magnetic Field, *The Physics of Fluids,* **Volume 5, Number 9,** 1057-1062, 1962.
2. Harris, E. G.W., and, Dienes, J.K., "Taylor Instability in a Viscous Fluid", *The Physics of Fluids,* **Volume 9, Number 12, 2518**-2519, 1966.
3. Barnes, J.F., Blewett, P.J., McQueen R.G., Meyer, K.A., and Venable, D., "Taylor Instability in Solids", *Journal of Applied Physics,* **Volume 45, Number 2, 727**-732, 1974.
4. Drucker, D.C., *Mechanics Today,* **Volume 5, Oxford**, Pergamon, 1980, 37-47.
5. Lebedev, A.I., Nisovtsev, P.N., and, Rayevsky, V.A.,"Rayleig-Taylor Instability in Solids", *The 4^{th} International Workshop on the Physic of Compressible Turbulent Mixing,* Cambridge, England, 29 March - 1 April 1993.
6. Swegle, J.W., and, Robinson, A.C., "Acceleration Instability in elastic-plastic solids. I. Numerical simulations of plate acceleration", *Journal of Applied Physics,* **Volume 66, Number 7, 2838**-2858, 1989.
7. Robinson, A.C., and, Swegle, J.W., "Acceleration Instability in elastic-plastic solids. II. Analytic techniques", *Journal of Applied Physics,* **Volume 66, Number 7, 2859**-2872, 1989.
8. Peterson, D.L., Bowers, R.L, Brownel, J.H., Greene, A.E., McLenithan, K.D., Oliphant, T.A., Roderick, N.F., and, Scannapieco, A.J., "Two-dimensional modeling of magnetically driven Rayleigh-Taylor instabilities in cylindrical Z pinches", *Physics of Plasmas,* **Volume 3, Number 1,** 368-381, 1996.
9. Roderick, N.F., and, Hussey, T.W, "Magnetic field diffusion effects on the hydromagnetic Rayleigh-Taylor instability", *Bulletin of the American Physical Society,* **Volume 28,** 1223, 1983.