Optimizing Kinetic Energy of Magnetically Driven Solid Liners for use as Drivers of HEDP Experiments

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Summary: This paper will show that it is possible to use 1D MHD simulations to select a starting radius and total mass combination for a cylindrical liner driven by a specific power source that will maximize the kinetic energy (KE) delivered to a target. Exploring this approach clarified the role specific time scales play in determining that optimum.

Introduction

Historical designs for cylindrical liner drivers have largely been constrained by simplified 1D approximation and an assumption of linear diffusion. Such analysis can be found in Knoepfel,'s book Magnetic Fields [1]. This approach has in been used extensively in selecting initial parameters for cylindrical liners. An additional perceived constraint has also been based on two further issues. The first issue is melting the outside surface of liner and the second issue is of course the feared onset of Magneto-Rayleigh instabilities in the fluid part and the subsequent destruction of the liner. These cautions limited the convergence factors ($R_{initial}/R_{final}$) of the liners to less than ten, limiting our parameter space, with only a few exceptions [2], to thicknesses in the millimeter range and starting radii of typically 5cm or less. Once these designs were selected, 1D and 2D simulations codes were utilized to test/predict the outcome of the experiments, but their utility was limited to testing variation on initial selections of designs.

This effort was inspired by the discussion in Knoepfel [1], chapter 6, pages 352-354, titled "Implosion of a cylindrical sheet. Specifically, the section is concluded with the statement "This problem can be solved only by numeric methods, even when the resistance is negligible that is $R << \sqrt{L/C}$. " The effort described in this paper uses 1D and 2D simulation codes to perform parametric scans of design parameters for liners being driven by several different types of pulse power systems. In particular the parametric variations are of liner mass and starting radius.

Discussion and Results.

The variations in mass and initial radius were conducted over a much broader space than typically has been considered. The types of drive systems examined include Marx bank systems including Atlas [3], a small Marx bank name Phelix, and the explosively driven Ranchero flux compression system [4]. An important note to make is when modeling dynamic systems such as flux compression power sources, representing these power sources as simple time dependant circuit parameters masked the predominant behavior of the total systems. When these power sources were modeled using full MHD simulations coupled to the MHD simulations of the load using self consistent circuit modeling, important features were revealed. These simulations were facilitated by the multi-MHD-module capability in the 1D Raven MHD simulation code [5].

The results of these simulations were very informative and have unveiled some rather surprising results. One result expands on the premise put forth in Knoepfel's book [1] regarding time scales (p 352). Specifically, the optimization of the energy delivered to the liner in the form of kinetic energy depends on the proper balance of three time scales: (1) the time scale of the delivery of magnetic field energy from the drive system, (2) the time scale for flux diffusion into the line surface and (3) the scale of the kinetic motion which is by nature of the cylindrical implosion a finite value. In the case where optimum conditions were found it was discovered that a specific balance of these three factors were observed. First, the magnetic field must achieve peak conditions relatively early in the process before much motion has occurred. Thus the liner is at a relatively large radius and hence the current density is relatively low, minimizing the conversion of field energy to internal energy. Second,

as the field peaks and then relaxes the acceleration begins to accumulate at a rate that compliments the reduction of field energy as the liner picks up velocity. If the acceleration is to fast (low mass) the pressure is released and the liquid material expands, increases resistivity and thermal runaway begins. Finally, the acceleration must be fast enough to complete as much conversion of field energy to kinetic energy before impacting on a target or the axis.

Illustrations and Photographs

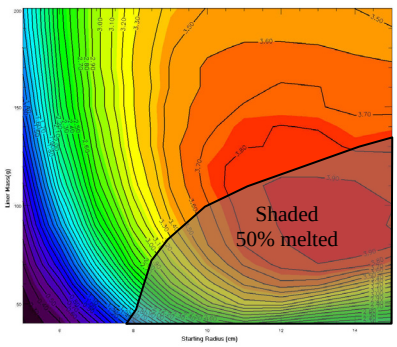

Fig. 1 Kinetic Energy (MJ) @ 1cm

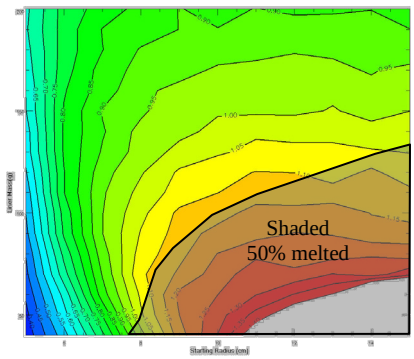

Fig. 1 Velocity (cm/ms) @ 1cm in

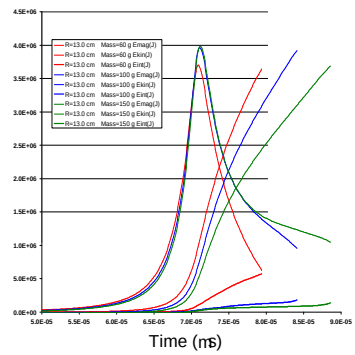

Fig. 3 Magnetic, Kinetic, Melt Time Scales

Conclusions

Figures 1 and 2 are example results from the Radius/Mass variations for the Ranchero drive systems driving a liner 4 cm in length that assume a target at 1cm radius. Varying the length has some effect but will not be discussed here. Several factors are evident in these pictures. First, while figure 2 shows large velocities for smaller masses at radii larger than 10cm. This region is useless for dense liner drivers as these thin liners are acting more like a fuse and the high velocity is for small remnants of the material after large fractions have vaporized. Second, Figure 1 shows the KE maximum is a broad area around a mass of 100 grams and a radius of 13 cm. However, this location is in a region where more than 50% of the material is melted and subject to instabilities unless other methods are use to minimize there effects [6]. The instabilities can be avoided by choosing values up and to the left above the 50% melted line. This would produce a liner that has KE ~3.8 MJ and velocity ~1.1 cm/ms. This suggests that in this case larger masses and larger radii than have been used in the past may be more appropriate.

A secondary discovery is the possibility to use other materials, for example copper, that have in the past been rejected because of the higher action to burst value of aluminum. To do so requires more attention to the three time scales as controlled by geometry and the time scale of the driving source. In general, the success of these studies lays the ground work for perhaps a straight forward methodical approach to designing optimum liners for specific drive systems.

References

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