Effectively Modeling Z-machine Wire Array Implosions

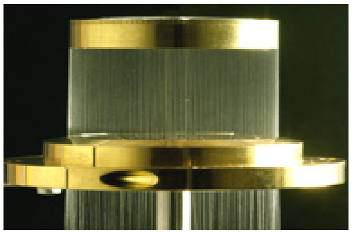

Figure 1: A wire array configuration used as a load for the Z-machine

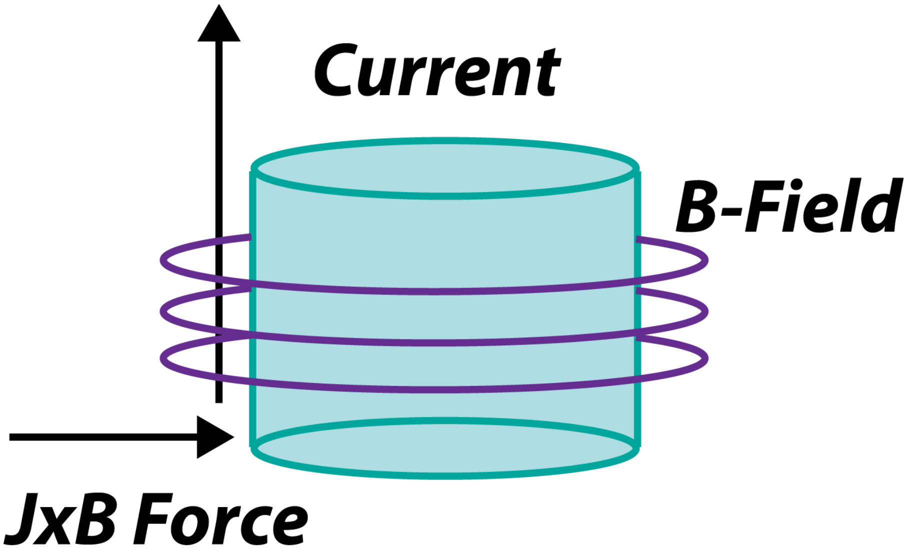

Figure 2: The current and associated magnetic field in the Z configuration drive a cylindrical implosion.

The ALEGRA magnetic-radiation-hydrodynamic code now has predictive capability for high energy physics

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The Z machine at Sandia characterizes high energy density matter under extreme environments. High magnetic fields are generated by wire-array implosions, where huge amounts of electrical current are run through a cylindrical array of tungsten wires (Figure 1). The magnetic field causes the wires to vaporize into a plasma and then drives the plasma toward the center axis of the array at high speeds (Figure 2). When this plasma stagnates at the axis, it generates considerable heat that exits the wire array as radiation. Modeling this highly energetic chain of events is enormously challenging because of the wide breadth of physics involved under extreme conditions.

Sandia's ALEGRA (Arbitrary Lagrangian-Eulerian) is a magnetic-radiation-hydrodynamic code that is designed to meet the challenge of modeling the wire-array implosion. ALEGRA has been around since 1994, but improvements in recent years have now enabled the effective simulation of wire-array implosions. A key enabling technology has been the implementation of a powerful solution to the magnetic portion of the problem using what are called compatible discretizations, which preserve the fundamental properties of magnetic flows exactly. In addition, codes like ALEGRA typically solve for the energy of the flow concentrating on the thermal content of the fluid. The problem is that flows like those found in a wire array are dominated by the energy of the magnetic field or the motion of the flow for significant portions of their evolution.

In fact, the process where the energy of the motion comes to a halt, when the flow hits the center axis of the wire array and is converted into heat, is essential. Therefore, Sandia had to modify the solution for the energy of the flow to more accurately account for this process and to rearrange the energy accounting in the flow so that it also could be accurately simulated.

With the utilization of the new methods in ALEGRA, in combination with an innovative technique for modeling the vaporizing wire array, it was discovered that one could now simulate wire-array implosions with enough accuracy that they could be compared favorably with experimental data (Figure 3). Furthermore, ALEGRA could be used to analyze and design follow-on experiments because of this predictive capability. This provided the scientists working on experiments in the Z-machine with new-found confidence in the predictive power of the simulations with ALEGRA.

Sandia continues to improve the algorithms by careful development and detailed analysis. A similar method has been developed for conserving magnetic energy as material moves through the computational mesh. Impressive improvements in shock test problems are observed by accounting for this energy (Figure 4).

References

R. Lemke, et al., "Effects of Mass Ablation on the Scaling of X-Ray Power with Current in Wire-Array Z Pinches," 16 January 2009 issue of *Physical Review Letters* (Vol.102, No.2): DOI: 10.1103/PhysRevLett.102.025005

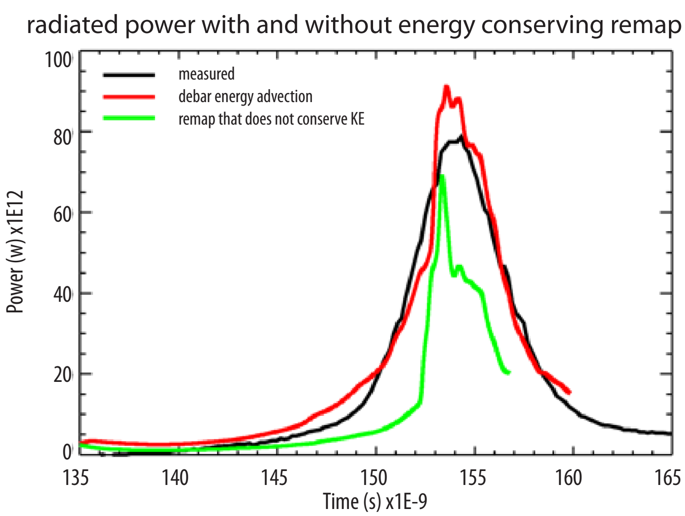

Figure 3: Algorithms to ensure that kinetic energy is preserved with material motion allow for vastly improved comparison with data.

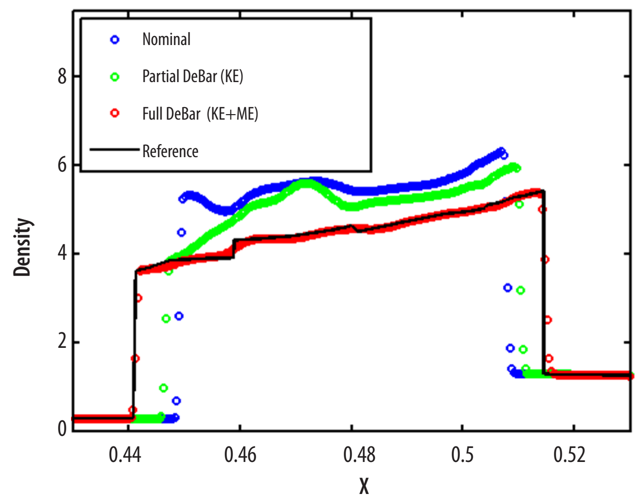

Figure 4: Magnetic energy conservation algorithm with material motion shows that additional quantitative jumps in solution accuracy are possible.