Supernova On Your Table Desk - Inertial Nuclear Fusion By Z-Pinch With A Hollow-Fiber Exploding Wire

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Abstract

The Z-pinch (or zeta pinch) is a type of plasma confinement system used in fusion power research. It relies on an electric current discharge within the plasma to generate a magnetic field that compresses the plasma, creating conditions conducive to nuclear fusion. The concept of Z-pinch has existed since the 1930s and represents a relatively straightforward design for achieving fusion. Recent research by Lawrence Livermore National Laboratory (LLNL) physicists has confirmed the existence of neutrons produced through thermonuclear reactions in a sheared-flow stabilized Z-pinch device, offering a promising pathway toward fusion energy.

In this approach we tried to simulate a multiphysics model that consists of a thin single hollow-fiber exploding copper wire, filled with nuclear fusion fuel material like Deuterium and Tritium (^2D and ^3T). Unlike the Sandia Lab's Z-machine that uses hundreds of parallel wires forming a 20cm long cylinder with some cm diameter.

The main idea was to force and tweak that system to reach the Lawson criterion in a simple and easy way, that means the system should produce net energy. The trick was not to use hundreds of wires shaping a cylinder shell, but use a single hollow-fiber metal wire instead. The inner diameter surface of the hollow-fiber metal wire will form an implosion, that compresses the nuclear fuel infill. One of the main advantages is, that the primary formed metal plasma has the generic density of the metal itself (copper : 8960 kg/m^3). So the following implosion shockwave can easily compress the nuclear fuel while adiabatic compression rises the temperature up to billions of K (in one of the simulated setups : 1.8e9 K) and about hundred Trillion Pa pressure, even without taking into account the Z-pinch (~9.0e13 Pa).

The simulation approach in this work uses a sequence of one-way coupled classical Multiphysics calculations with some very rude simplifications and assumptions. The simulation steps are as follows:

1) Estimation of the rise time of the exploding wire discharge breakdown. Assumptions : the breakdown time can be estimated by a given electric charge (capacitor C) Q and U {U(t) = L di(t)/dt}. The inductivity of the circuit is estimated by Comsol Multiphysics, while the electric conductivity is based on a 100% ionised plasma.

2) Joule heating of the wire by electric discharge {W = 1/2 C U^2} . Assumptions : the system behaves adiabatic while the discharge time can be run in less than t << 1.0 ns , so radiation can travel at the speed of light at most L << 0.3m distance. The solid and liquid and gas phase state of matter can be neglected in favor of the plasma state, because heat capacity and temperature range is significantly lower than that of the plasma state. So the metal plasma can be modeled very simplificated as a 1-atomic ideal gas with the heat capacity of {c_v = 3/2 R} or {E_kin = 3/2 k_b T}.

3) Adiabatic compression of the plasma by forming a shockwave using compressible euler

equations. Assumptions : as in the step above the metal plasma is treated like a 1-atomic ideal gas with the starting condition density of solid copper and the temperature calculated in step 2.

4) Z-Pinch by current discharge in the metal plasma. Assumptions : the Z-pinch deformation of the plasma by the electromagnetic field is calculated by the structural mechanics module as a pseudo-elastic body. The Young's modulus E can be expressed by the plasma compressibility {E = d(p)/d(rho) = R_copper T}

Next steps will try to run the whole or parts of the system as fully coupled Multiphysics simulations and respecting the radiation heat loss.

Reference

https://www.sandia.gov/z-machine/

https://www.llnl.gov/article/48501/llnl-scientists-confirm-thermonuclear-fusion-sheared-flow-z-pinch

http://www.belljar.net/Exploding_Wires.pdf

https://en.wikipedia.org/wiki/Lawson_criterion

Figures used in the abstract

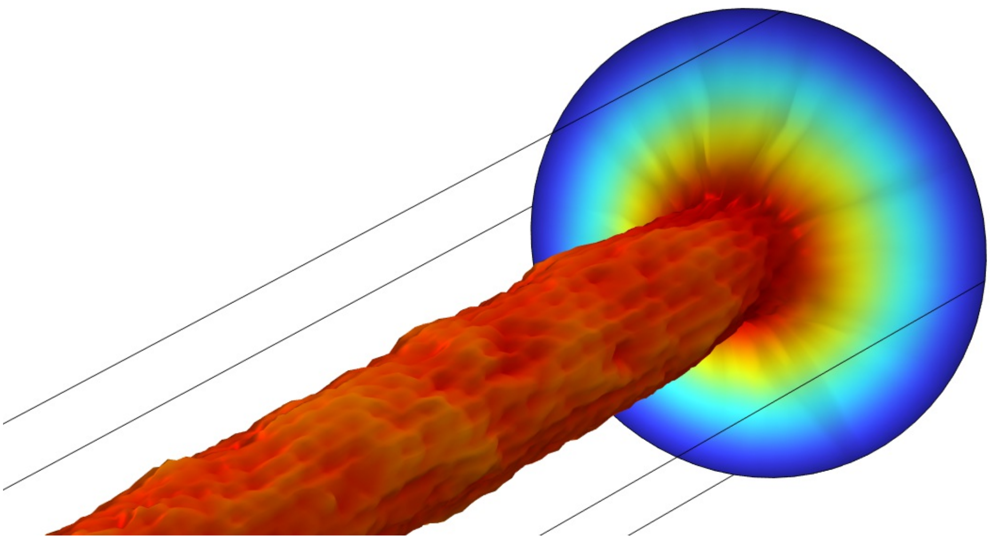

Figure 1 : Fig. 1 : Z-pinch of metal plasma compression

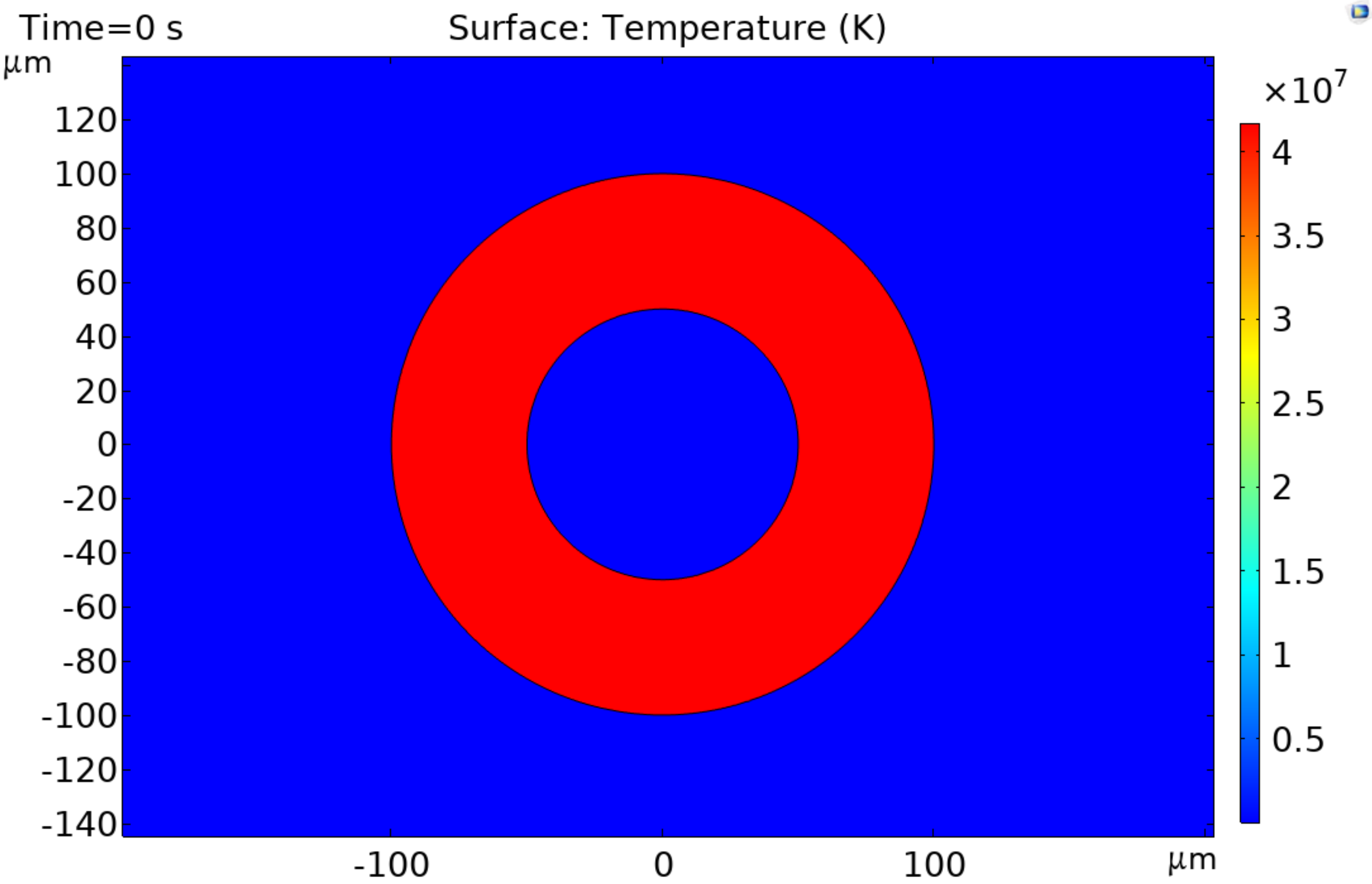

Figure 2 : Fig. 2 : Exploding hollow-fiber wire cross section starting temperature of metal plasma

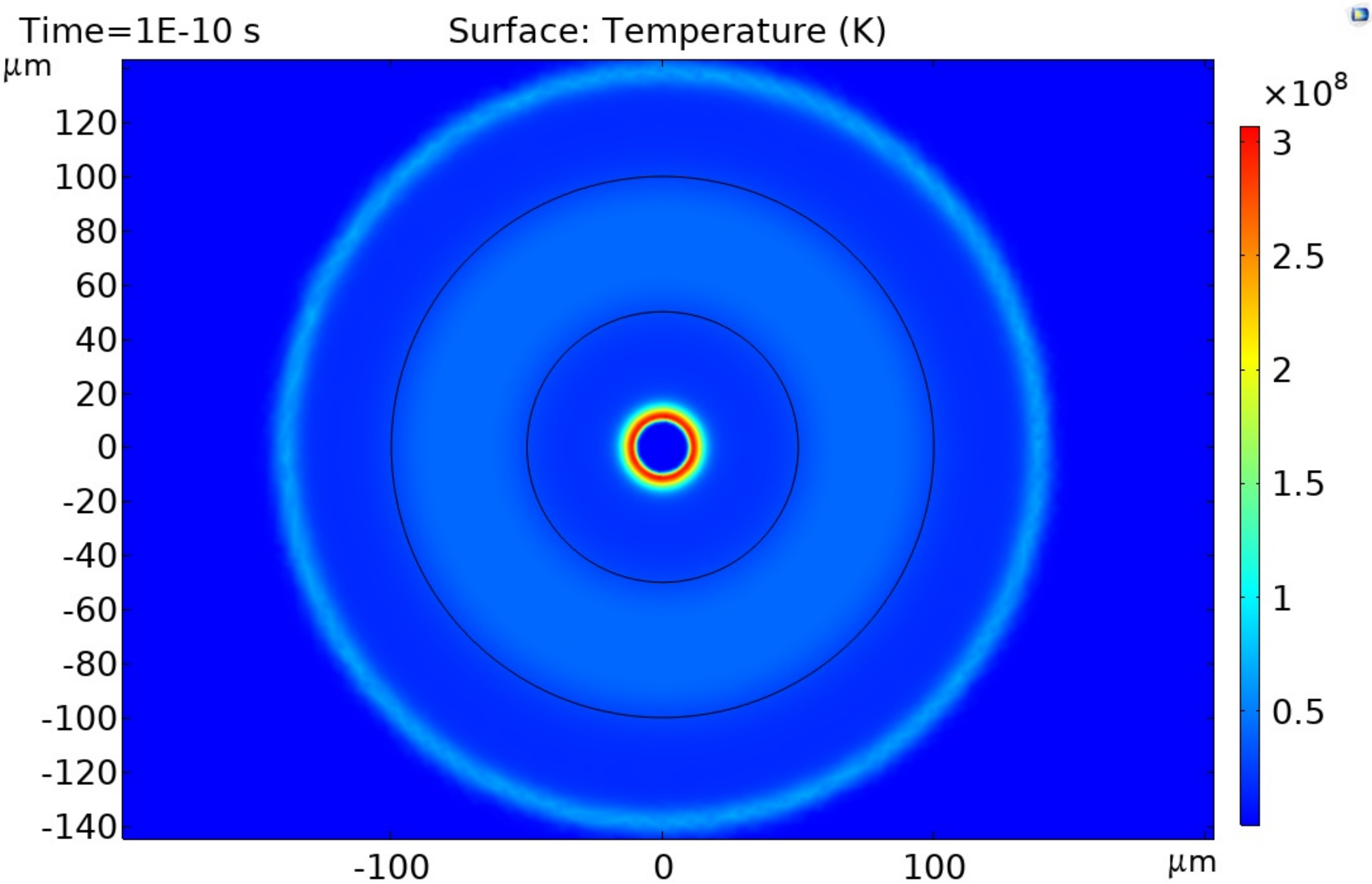

Figure 3 : Fig. 3 : Temperature of metal plasma just before temperature maximum

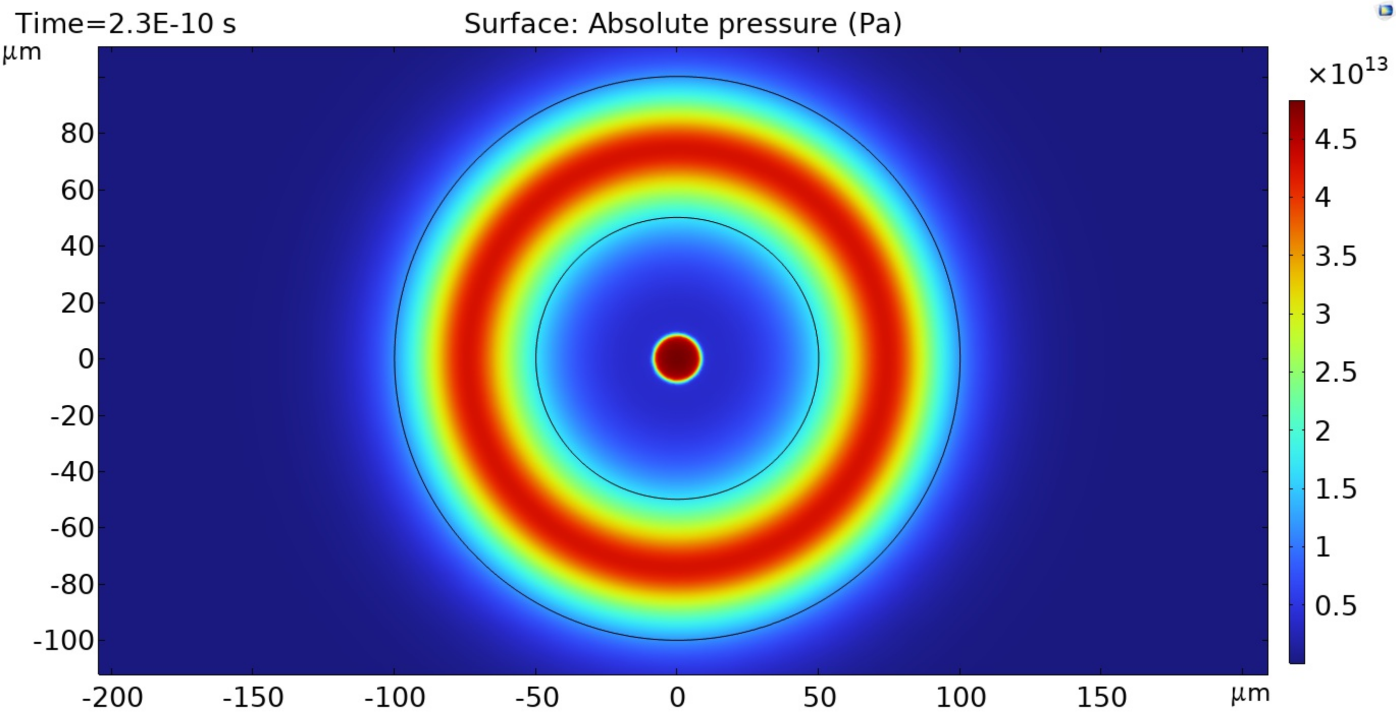

Figure 4 : Fig. 4 : Pressure of metal plasma just before pressure maximum