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COPPER TUBE COMPRESSION IN Z-CURRENT GEOMETRY, NUMERICAL SIMULATIONS AND COMPARISON WITH CYCLOPE EXPERIMENTS

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Metallic tubes compressions in Z-current geometry were performed at the Cyclope facility from Gramat Research Center in order to study the behavior of metals under large strain at high strain rate [1].

3D configurations of cylinder compressions have been calculated here to benchmark the new beta version of the electromagnetism package coupled with the dynamics in Ls-Dyna and compared with the Cyclope experiments.

The electromagnetism module is being developed in the general-purpose explicit and implicit finite element program LS-DYNA® in order to perform coupled mechanical/thermal/electromagnetism simulations. The Maxwell equations are solved using a Finite Element Method (FEM) for the solid conductors coupled with a Boundary Element Method (BEM) for the surrounding air (or vacuum). More details can be read in the reference [2] [3].

1.1 CONFIGURATION OF THE NUMERICAL SIMULATIONS

The numerical configuration is presented Figure 2. The cylinder is 70 mm in height, inner radius is 9.3 mm, and external radius is 9.8 mm. There are 32 elements in height and 10 elements on the thickness.

The cylinder is connected on both sides to a circuit with a capacitor bank. For the numerical simulations, the experimental current is injected on one side of the finite element cylinder as input data.

3D configurations, built with the TrueGrid® mesh generation program, have been used with a lagrangian description.

Many parameters have been investigated to study the motion of the inner diameter of the cylinder submitted to Z-geometry high current:

- The influence of number of cycle for the current calculation
- The influence of the constitutive laws
- The influence of the thermal analysis solver
- The influence of the diffusion of the current in the volume

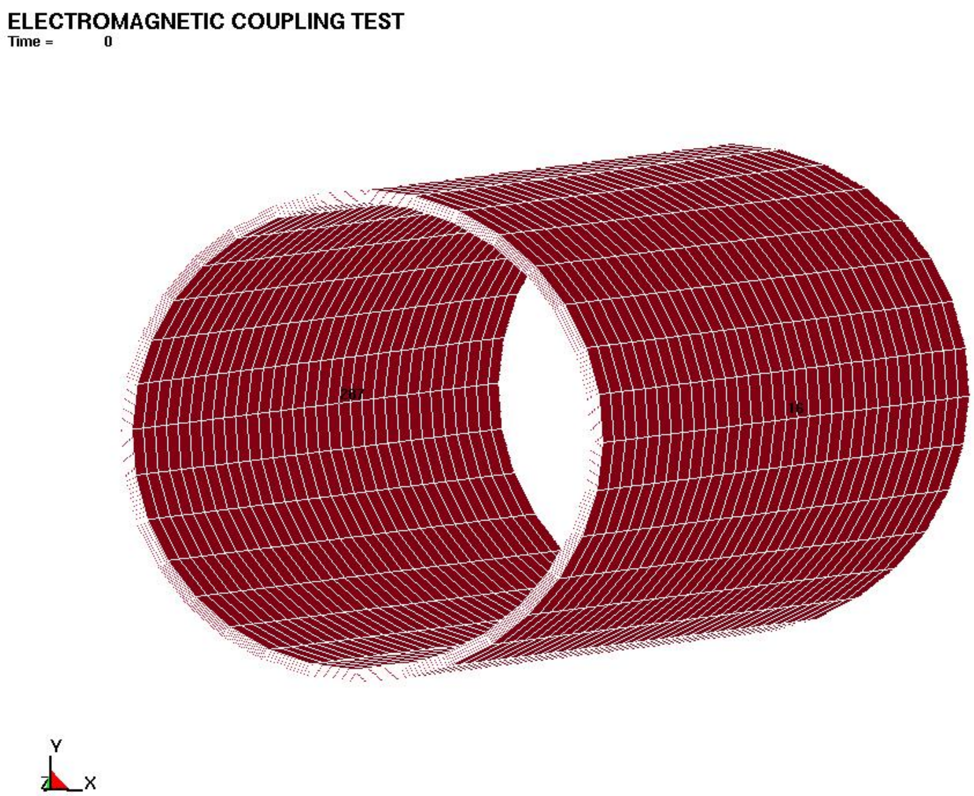

Figure 1 : Configuration of the numerical simulation for the Cyclope experiments [1]

1.2 MODELS DESCRIPTIONS

Two constitutive laws have been used for the copper cylinder: Steinberg and Johnson-Cook equations [4][5]. A classical Gruneisen equation of state has been applied. The heat capacity and the thermal conductivity are needed to run the thermal solver. The Joule heating and the plastic work heating could then be taken into account.

The main assumptions are no phase change, no plasma, conductivity constant for the anode and cathode. The diffusion of the current has been taken into account. It is possible to take into account the conductivity change versus the temperature (resistivity equation of state), but has not been tested yet here. Further studies should take these into account.

1.3 NUMERICAL SIMULATION RESULTS

The numerical results are presented Figure 2, Figure 3 and Figure 4. They are given for a cross-section in the middle of the cylinder.

The two constitutive laws show the same numerical displacement for the 20 electromagnetism cycles for the all run.

The influence of the electromagnetism time step is important. The mechanical time step is about 10 ns. The electromagnetism time step has been tested with 0.1 microsecond, 1 microsecond and 20 microseconds, corresponding respectively to 200 cycles, 20 cycles and 1 cycle during the run, which has about 2000 mechanical time steps (figure 2).

The diffusion of the current in the volume of the copper cylinder reduces slightly the displacement of the cylinder, compared to the assumption of a surface conduction (figure 3).

The thermal solver allows calculating the temperature of the copper. The temperature is 220 Celcius for the inner diameter at 14 microseconds, and 400 Celcius for the outer diameter. The temperature drops very fast on the 4 first outer elements of the cylinder, where most of the current flows (figure 4).

It is also possible to output the magnetic field, the current density, the lorentz force, and other electromagnetism characteristics, see Figure 5 and Figure 6. When the current becomes negative, the magnetic field vector also changes on the outer diameter after 15 microseconds, which induces a change on the Lorentz forces.

Further analysis is needed to address also the effect of the mesh density.

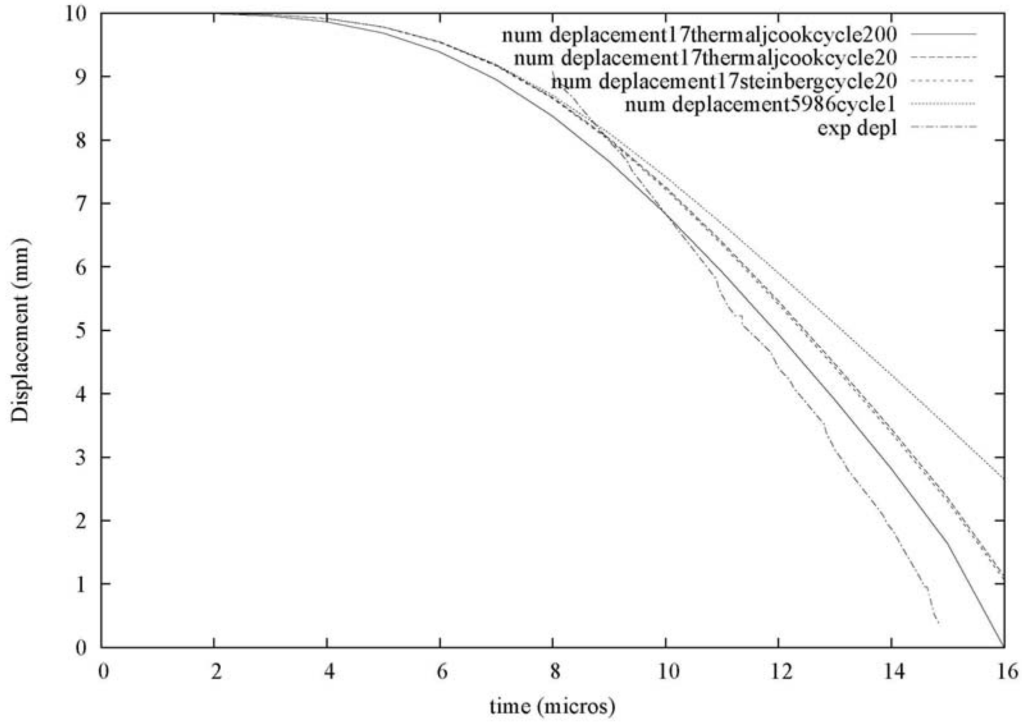

Figure 2 : Displacement of the inner diameter versus time, Cyclope experiment (1.8 MA quarter cycle time 7 microseconds) compared with numerical simulations

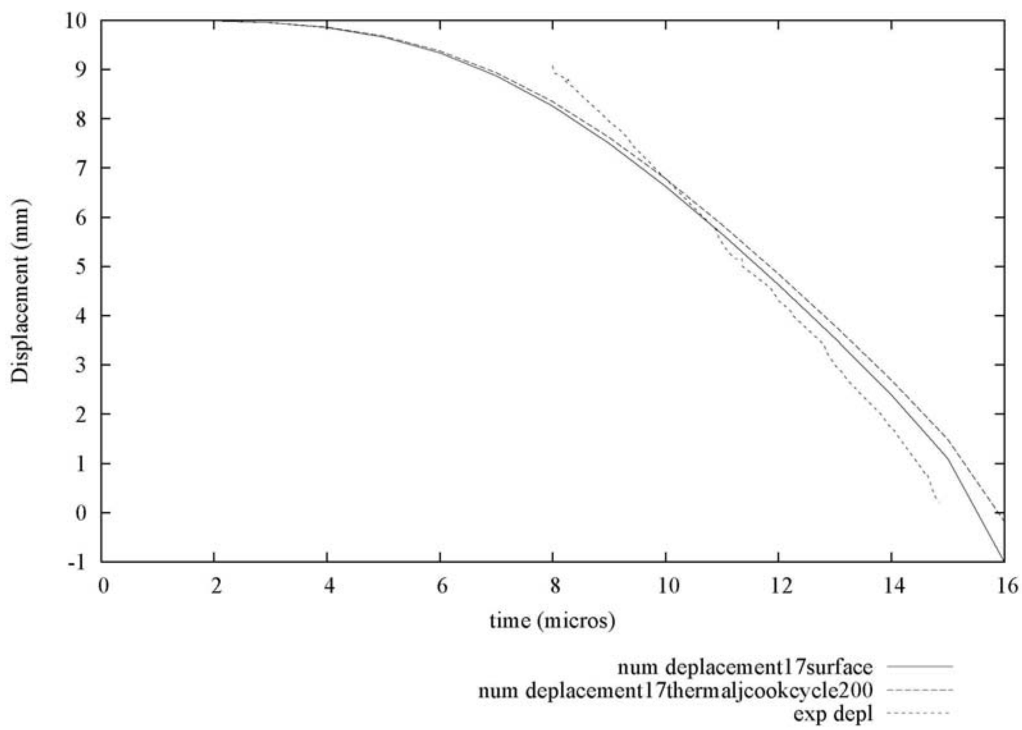

Figure 3 : Displacement of the inner diameter versus time, Cyclope experiment (1.8 MA quarter cycle time 7 microseconds) compared with numerical simulations

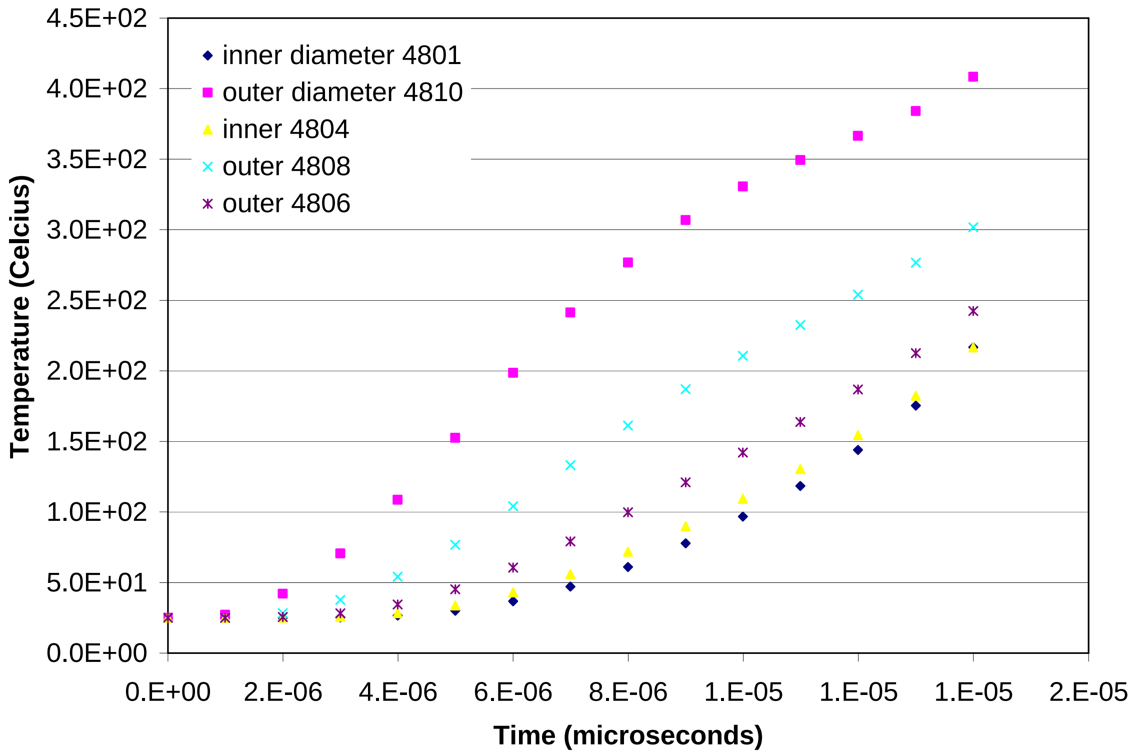

Figure 4 : Numerical simulations of the temperature in the Cyclope experiment (1.8 MA quarter cycle time 7 microseconds)

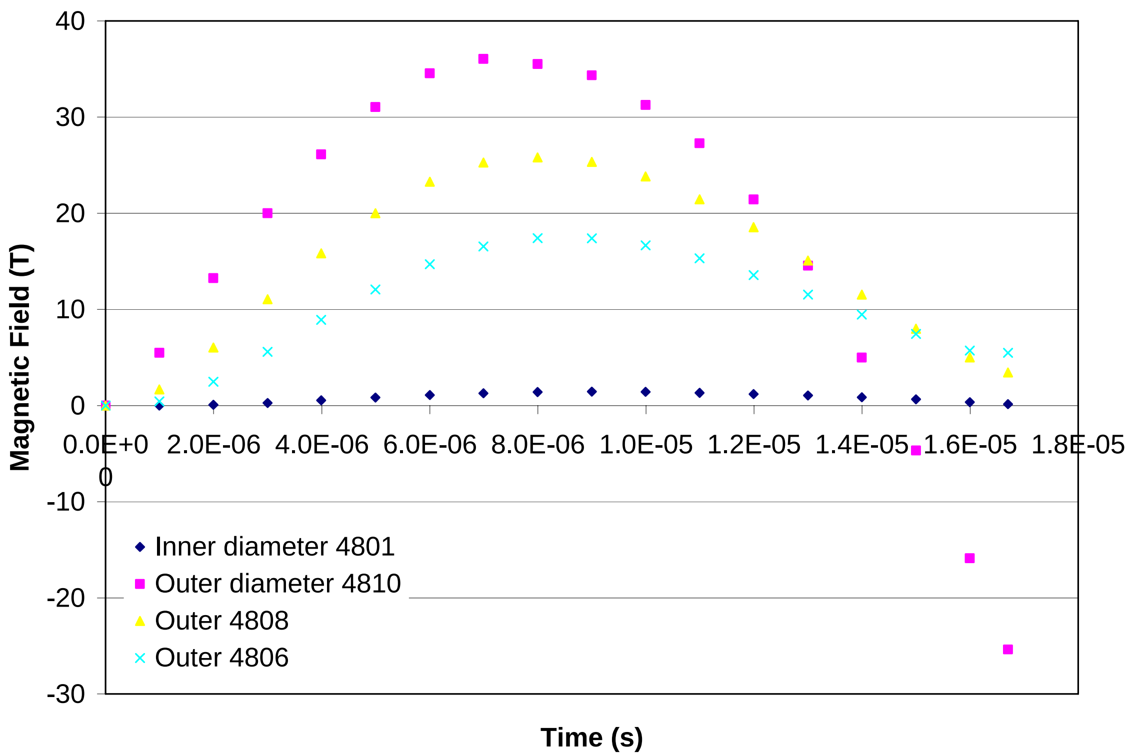

Figure 5 : Magnetic field versus time, numerical simulations

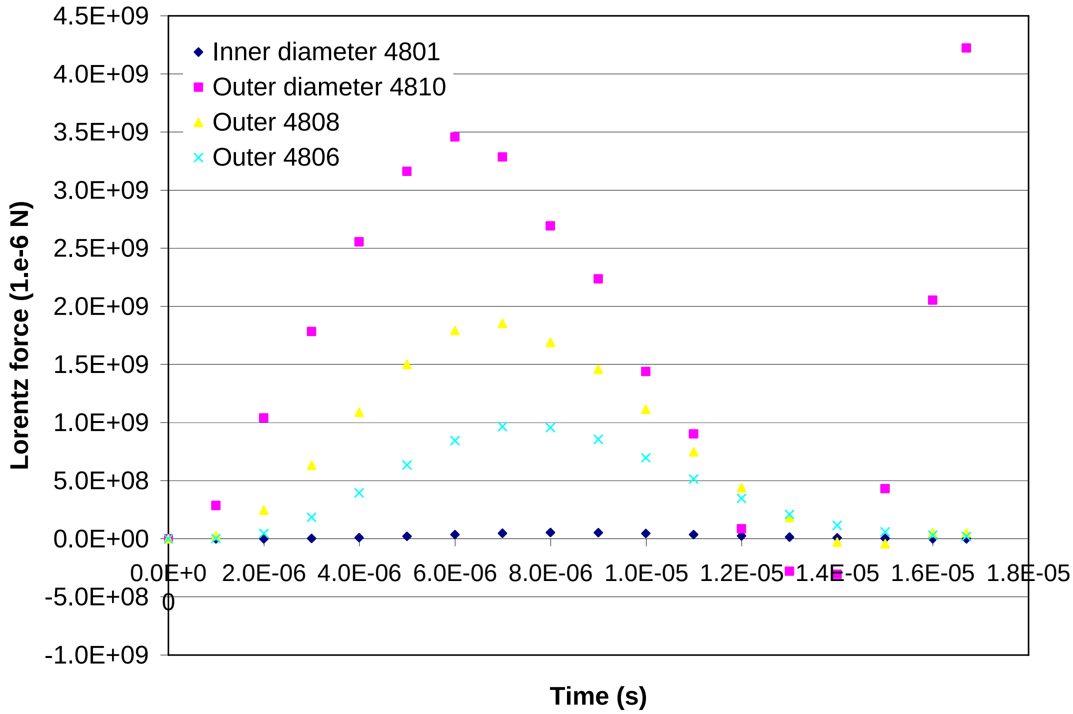

Figure 6 : Lorentz forces versus time, numerical simulations

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