Numerical simulation of current sheet instabilities in a small plasma focus

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Abstract. A comparison between numerical simulations of discharges in the Plasma Focus device PF-50J using the code Cshock is presented. The code was able to reproduce kinetics and circuit parameter experimental measurements as well as the particular current sheath instability observed in this specific device.

1. Introduction

The computer aided optimization of plasma-focus (PF) devices requires the calculation of the sheath movement and the sensibility of the process to geometrical and operational parameters. This calculation involves the tracking of the ionizing shock accelerated to hypersonic velocities. During the displacement, the shape of the current sheath changes, inducing, in turn, variations on the boundary conditions, the forces and on the dissipation rates. CShock [1,4] is a numerical code of PF discharges based in a two-dimensional description of the current sheath (CS), which is represented by means of a set of dynamic conical elements moving and reshaping themselves according to the conservation equations of mass, momentum and energy [2]. The code showed good performance in tracking the current sheath in various PF and recently it was used to calculate the neutron production in a pinch [3]. In the present paper, Cshock is applied to simulate the CS evolution in a small plasma focus where the rundown and runover stages overlap.

2. The model

A PF consists basically of two coaxial electrodes, inner anode and external cathode, separated by an insulator material at one end. The space between electrodes is filled with low pressure gas and, when pulsed high voltage is applied between the electrodes, a discharge starts over the insulator from which the plasma sheath take-off axially accelerated by the magnetic field generated by the current itself. In cases where the cathode is just a planar plate, the current sheath expands freely radially away from the axis. The evolution of the mass (*m*) and momentum (*mv*) of a CS element of area *A* (Fig. 1), length *l*, velocity *v*, located at radius *r,* follows:

$$\frac{dm}{dt} = \rho A v \qquad (1)$$

$$\frac{d(mv)}{dt} = \frac{\mu_o}{4\pi}\frac{l}{r}I^2 \qquad (2)$$

Where ρ is the stagnant density and I is the electrical current, which is calculated from the equation of an electrical circuit with variable inductance:

$$\frac{d}{dt}\left[\left(L_{ext}+L_g\right)I\right]+R_{ext}I+\frac{Q}{C}=0 \tag{3}$$

$$\frac{dQ}{dt}=I \tag{4}$$

In Eqs. (3) and (4), L_{ext} and R_{ext} are the external inductance and resistance, L_g is the variable inductance associated to the coaxial gun, and Q and C are the bank charge and capacity.

Figure 2 shows a 3D visualization of the current sheath representation. The sheet is re-structured every step in order to maintain a uniform number of nodes per unit length (in the present case 3 nodes per mm).

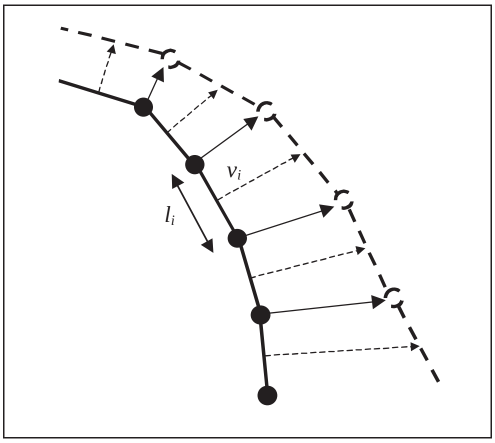

Figure 1. Diagram of the numerical calculation of the movement and shaping of the current sheath.

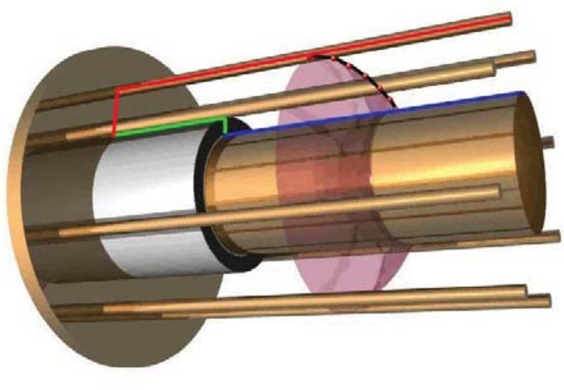

Figure 2. Visual representation of the discretization of the current sheath.

3. Results

Cshock was applied to calculate the shape evolution of the CS in the PF device PF-50J [1], which was compared with experimental visualizations and electrical diagnostics. The electrical parameters used in the simulation were: capacity 158 *nF*, external inductance 41.6 *nH*. The geometrical parameters were: anode radius and length 3 and 27.9 *mm* respectively, insulator radius and length 4.7625 and 23.9 *mm* respectively. The operation parameters were: D_2 filling pressure 6 *mbar* and charging voltage 29 *kV*. It should be stressed that Cshock does not require the introduction of sweeping parameters since, unlike the planar pistons models [5-6], the shape of the current sheet is solved along with the evolution of the electrical and thermodynamic variables.

Figure 3 shows the evolution of the electrical current and the minimum radial position of the sheath. It can be seen that the numerical calculations reproduces well the experimental trend. Figure 4 compares the calculated shape of the current sheath at different times with the shape deduced from interferometrical measurements. It is interesting to observe that the code was able to reproduce a singular elbow observed immediately after the lift-off of the plasma sheet. The singularity is produced in the code by an instability brought about by a local accumulation of mass which start at the border of the insulator. Figure 4 shows the mass distribution along the CS, where a peak density appears where the CS presents a singular elbow.

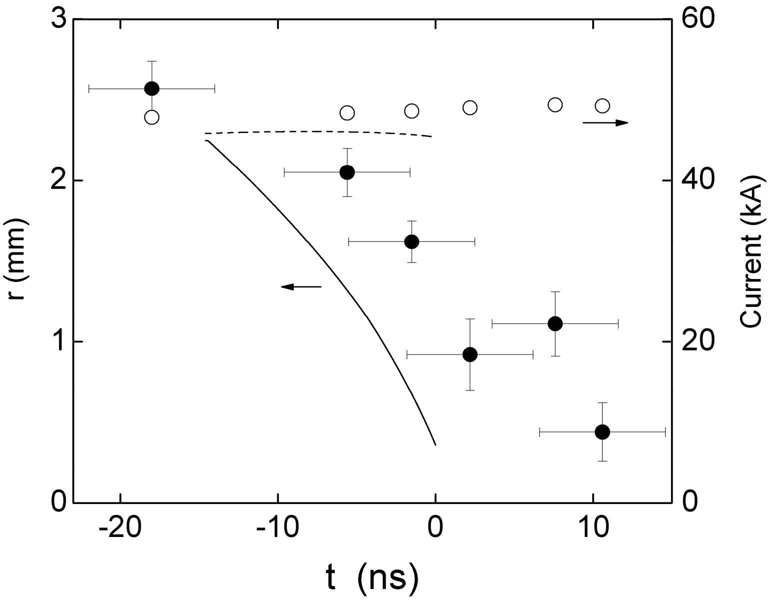

Figure 3. Evolution of the radial position of the current sheet (full and solid) and the electrical current (void and dashed). Experiment (points) and numerical results (curve). The time *t* is measured relative to the pinch.

4. Conclusions

A two-dimensional model of the current sheath dynamic shaping in discharges on a small 50 kJ plasma focus was presented. The code was able to reproduce kinetics and circuit parameter experimental measurements as well as the particular current sheath instability observed in this specific device. The singular trend of the sheath observed in the initial stages of the discharge is reproduced by the numerical model, where it is caused by an instability brought about by a local accumulation of mass which start at the border of the insulator.

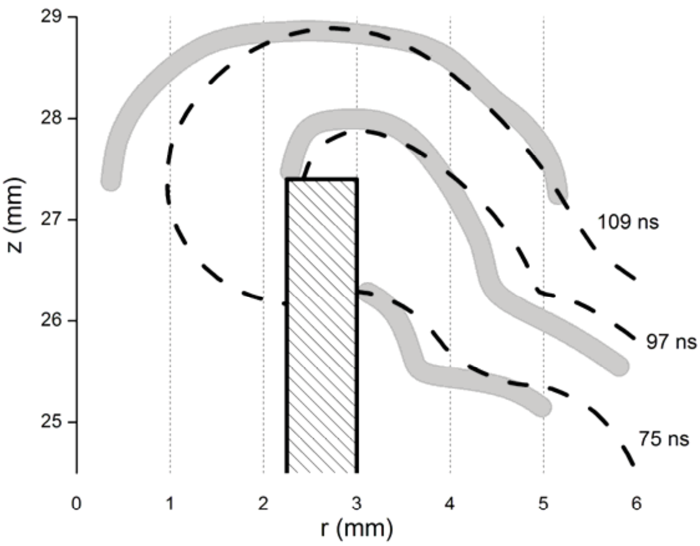

Figure 4. Shape of the current sheet at different times. Numerical (dash), experimental (solid grey). The numbers at the right indicate the corresponding time after the closure of the spark gap.

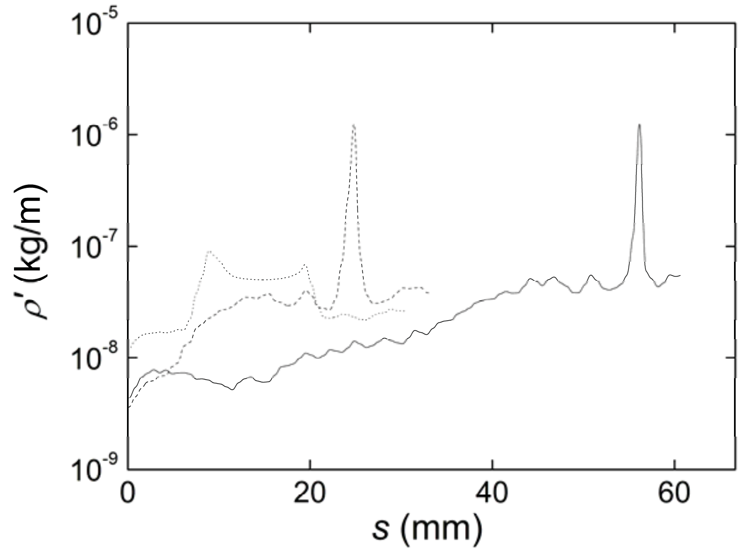

Figure 5. Linear density of the nodes of the current sheet at 75 ns (dots), 97 ns (dashes) and 109 ns (solid). The coordinate *s* represents the position along the CS starting at the anode.

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