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Investigation of regimes of wire array implosion on the Zebra accelerator

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Imploding of a wire array z-pinch is presently the most powerful laboratory source of soft x-ray radiation [1]. Investigation of the wire array implosion dynamic is important for the development of the Z-pinch physics. Details of the implosions vary in experiments at different generators [2, 3]. Investigations in facilities with different parameters deliver data for optimization of wire arrays and for scaling it to multi-MA generators.

Implosions in Al and Cu wire arrays were studied in Zebra generator with multiframe optical probing and x-ray gated diagnostics. High-resolution laser probing diagnostics together with the x-ray gated diagnostics allowed observation of different regimes of Z-pinch implosion in the low wire number arrays.

Different regimes of implosion were observed in "light" (33-37 μg/cm, R=16 mm) and "heavy" (66-75 μg/cm, R=16 mm) Al loads [3]. Implosion of Al loads with mass 33-37 μg/cm produces the dense pinch with streams of extending material on the rising edge of the radiated x-ray pulse. In this regime the precursor collapses at the time of implosion and plasma is confined in the core 1-1.5 mm in diameter and in the trailing mass. In Fig. 1 the z-pinch is subjected to strong instabilities at the time of stagnation. Six-wire Cu arrays (46 μg/cm, R=12 mm) showed shadowgrams of implosion very similar to the regime in the "light" Al arrays. The FWHM duration of the x-ray pulse was ~30 ns for the "dense pinch" regime. Instabilities are seen in x-ray gated images in Fig. 3a. After the maximum of the x-ray pulse the pinch transforms to a chain of bright spots with the kink instability. Dynamics of x-ray images are similar to shadowgrams.

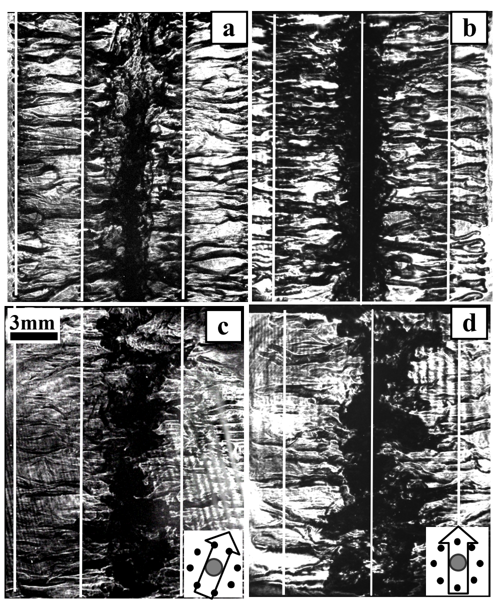

Fig. 1. Shadowgrams of the Al 8x15μm wire array in the dense pinch regime of implosion. Left lower corner of images c and d shows the direction of laser probing. Timing of the frames from the starting point of the current pulse is 121 ns (a), 130 ns (b), 146 ns (c), and 155 ns (d).

In the implosion of "over-massed" Al loads a plasma column collapses on the fallen edge of the x-ray pulse. Figure 2 presents shadowgrams and a timing diagram of the current pulse and x-ray pulse of the Al 8x20 μm wire array. The dense core is not subjected to the kink instability and transforms to the chain of dense spots in the later stage. In Fig. 3b x-ray images look like a vertical chain of hot spots and the pinch is not distorted by the kink instability. The duration of the x-ray pulse is 30-50-ns and the pulse has a long tail with a post-pulse. The average radiated energy in these loads is 2 times less than in the "dense pinch" regime

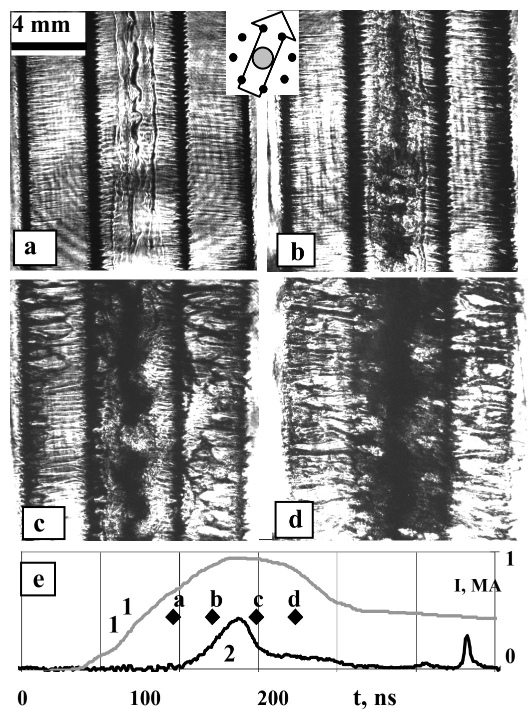

Fig. 2. Images a, b and c, d present two 2-frame shadowgrams of implosion in the 8 x 20 μm wire array; e – the timing diagram. 1 – the current pulse; 2 – the x-ray pulse; diamonds - optical frames.

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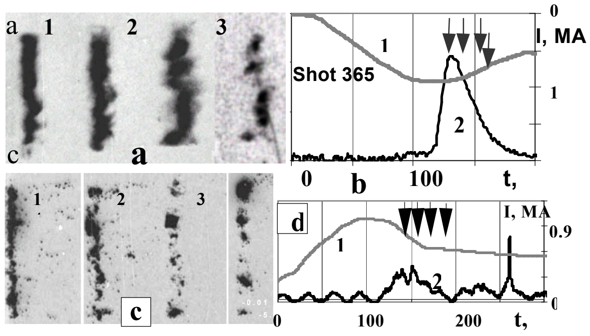

Fig. 3. a, c – x-ray gated images >1 keV; a - the implosion in the Al 8x15μm (dense pinch); b – the implosion in the Al 8x15μm (soft pinch). b, d – appropriate timing diagrams; 1- the current pulse; 2 – the

of the implosion. Implosion occurs on the falling edge of the x-ray pulse. This implosion does not produce powerful x-ray radiation, presumably, because the kinetic energy of imploding mass decreases. Implosion of 8-wire Cu arrays (62 μg/cm, R=16 mm) showed a regime similar to the regime in heavy Al arrays.

Larger radiated x-ray energy suggests that the dense pinch regime provides better implosion quality, timed near peak current. Heavier arrays do not reach the dense pinch regime due to a later implosion. The different regimes of implosion at the Zebra accelerator could be explained by different current regimes in the dense pinch and in heavy loads.

Different implosion dynamics were observed in Al 8-wire arrays with 15-μm wires (37 μg/cm). Two types of images in the z-pinch implosion have been seen by optical diagnostics. A high contrast image of the pinch with the dense, opaque column on the axis and streams of extending material is typical on the rising edge of the x-ray pulse. The pinch is subjected to strong MHD instabilities. In another regime the plasma column of the precursor arises at the time of the prepulse of the x-ray radiation. A chain of dense spots along the axis with the transparent remnant plasma column is seen at the maximum of the x-ray pulse in the shadowgrams.

A 3-D hybrid simulation of ideal and non-ideal MHD regimes of implosion was carried out to model soft and dense pinches [4]. Simulation of a plasma current-carrying column with radial density profiles and Hall parameters corresponding to those obtained during Al wire array implosions were carried out. Two regimes of sausage and kink instability development with two values of the Hall parameter $\varepsilon_H = 0.01$ and $\varepsilon_H = 0.04$ were analyzed. 3D hybrid simulations of a plasma current-carrying column with density profiles observed during the after implosion stage of wire array shots at the NTF revealed two regimes of sausage and kink instability development. In the first regime in Fig. 4 (a), with a small Hall parameter, development of instabilities leads to the appearance of large-scale axial

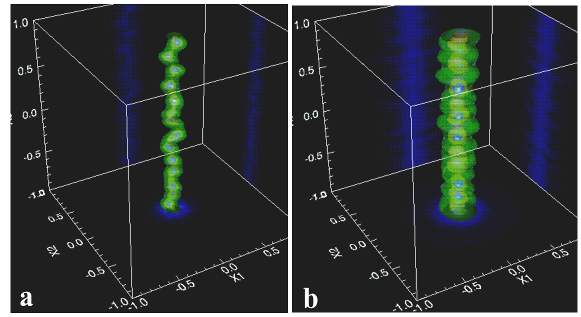

Fig. 4. 3D plots of plasma density with the Hall parameter ε_H = 0.01 and B_0 =1 (ideal regime, a), ε_H = 0.04 and B_0 =0.2 (non-ideal regime, b).

perturbations and eventually to the bending of the plasma column. In the second regime in Fig. 4 (b), with a four times larger Hall parameter, small-scale perturbations dominated and no bending of the plasma column was observed. Simulation results are in qualitative agreement with the experimental results.

In conclusion, different regimes of implosion in Al, and Cu wire arrays were observed at the Zebra accelerator. Light Al and Cu loads implode to the dense narrow pinch with strong MHD instabilities. Over-massed Al and Cu wire arrays shows a plasma column with axial pinch that is not subjected to the kink instability. In the wire arrays with larger mass, the implosion does not reach the dense pinch regime of implosion, presumably due to later implosion, when a significant part of the current is switched to the plasma column. 3D hybrid simulations of z-pinch with two values of the Hall parameter demonstrate a good qualitative agreement with the experiments.

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