WILD CABLES IN A Z-PINCH AND PLASMA FOCUS

A.B. Kukushkin, V.A. Rantsev-Kartinov
INF RRC "Kurchatov Institute", Moscow 123182 Russia

The progression of the input energy in Z-pinches is under reconsideration in the very recent time (see [1]). Such a necessity comes from recent observations of an enhanced coupling of the magnetic energy to strongly radiating wire-array Z-pinches (see [2] and references therein). In particular, the measured total X-ray yield appears to exceed, sometimes by a factor of few-several units, the estimated thermalized kinetic energy of the imploding annular plasma column. Besides, the anomalously high rate of the «direct» (non-kinetic) dissipation of the magnetic field in the Z-pinch at stagnation has to be explained. The buoyancy of magnetic flux tubes converging through the quasi-steady-state MHD-unstable Z-pinch plasma was proposed [1] to be responsible for the latter phenomenon. Such an approach may be interpreted as a sort of nonlocal (non-diffusive) mechanism of the magnetic field transport toward the Z-pinch axis at stagnation.

Here, we present the data from earlier experiments with a gaseous Z-pinch, which suggest the presence of another mechanism which may also contribute to the nonlocality of radial transport of energy. These data show the fine structure of the formerly observed [3(a,c),4] long-living radially-directed filamentary structures. The anomalously high survivability of such filaments was illustrated via 3D imaging of the history of a typical straight rigid-body block (~2 cm long, ~1 mm in diameter, see Fig. 1 in [4]). Those pictures were taken in the visible light at different time instants from different positions, during about half a microsecond, that is comparable with the entire duration of the Z-pinch discharge and dramatically, by the orders of magnitude, exceeds the lifetime of sustaining the rectilinearity by a long fluid filament directed nearly perpendicular to the total electric current through the Z-pinch.

The resolution of the fine structuring comes from the results of processing the images with the help of the method of multilevel dynamical contrasting (MDC) [3(a,b)] (note that sometimes the large scale structuring may be seen even without MDC processing). The reliability of the results is based on the rich statistics, considerable similarity of the observed structuring in various regimes and various facilities (including the Z-pinches and plasma foci), as well as the insensitivity to specific way of imaging (including, e.g., electronic optical converter, photography with a high-speed shutter).

Major attention was paid to identification of straight filaments directed nearly radially (see Figs. 1-4). The typical straight filament appears to be a cylindrical formation varying in length from few millimeters up to the radius (and even diameter) of the chamber. Such filament has an axisymmetric tubular sheath, with a distinct boundary and, often, a distinct inner cylinder that makes the entire formation very similar to a coaxial cable (see, e.g., central window in Fig. 1, and Fig.4). These features appear to be similar to those of the structures recently found [5] in the visible light databases taken from a number of small and moderate size Russian tokamaks (see also paper P2.029 at this conference).

The similarity of the observed structures to coaxial cables may appear to be not occasional: according to hypothesis [5] the elementary straight block (in tokamak case, of diameter not exceeding few millimeters) may work as a «wild cable» in which the propagating high-frequency (HF) electromagnetic wave produces a vacuum channel around a hypothetical microsolid skeleton [4] and thus protects, by the Miller force, the skeleton from the ambient high-temperature plasma. In the wild cable, the skeleton works as a waveguiding rod, and the ambient plasma, as a screening conductor (for detail, see also paper P2.028 at this conference).

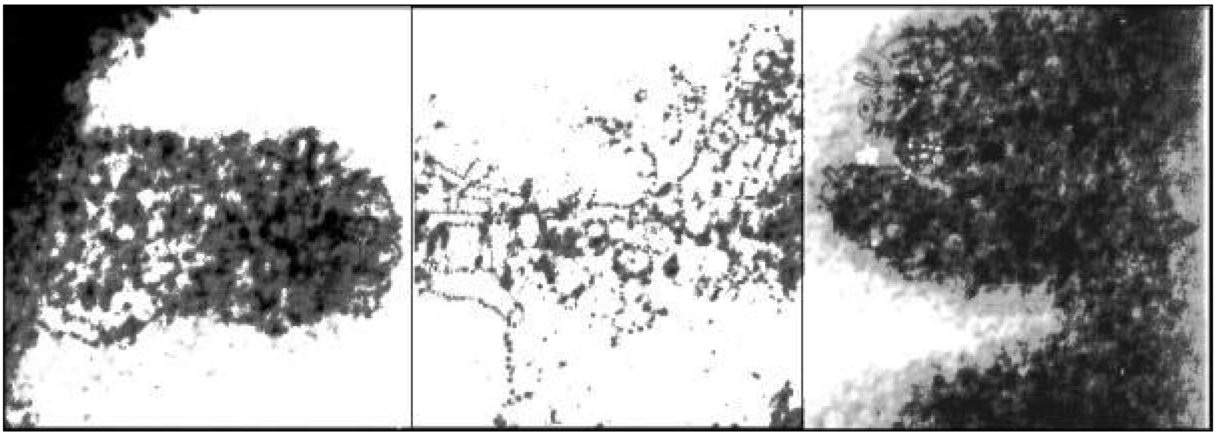

Fig. 1. Visible light picture (positive) of a layer, 7.5 cm wide and 5 cm thick, located near the axis of a gaseous Z-pinch in the neck region at time t=+50 ns after major singularity of electric current (the layer is «extracted» by the optics collecting the light). The chamber is 60 cm long and 20 cm in diameter, major axis is directed vertically, maximal current ~ 360 kA, working gas deuterium, time exposure 10 ns (for other experimental conditions see [3(a,c)]). The original image is processed with the method of multilevel dynamical contrasting [3(a,b)] with different maps of contrasting in central and peripheral windows to show the continuity of the structuring in the regions of substantially different luminosity. Dendritic tubular filaments (of a diminished luminosity, with respect to strong background) in the central section are of diameter d = 0.7 - 1.5 mm, while thick fractal formations («dark filaments») in the neck, in the left and right windows, are of d ~1.2 and 0.5 cm, respectively.

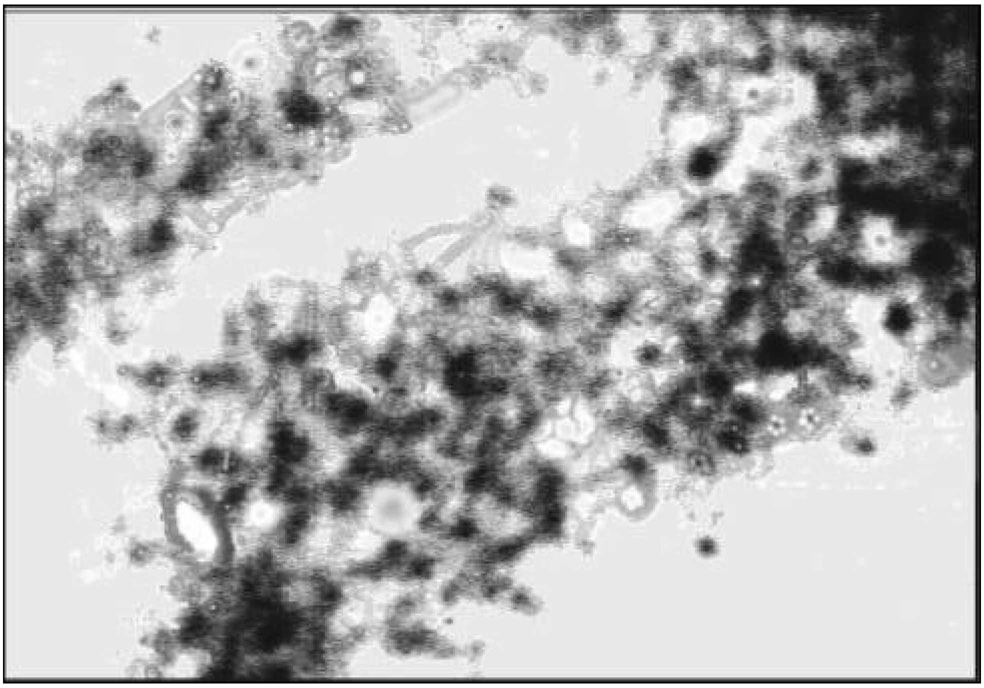

Fig. 2. Typical radially directed filamentary formation in the Z-pinch (major conditions are similar to those of Fig.1). Here, the axis of the Z-pinch is located at the left edge of the image, time t =+300 ns, image width 3.5 cm (positive), diameter of a ring at the left edge of a dark fractal filament is ~3 mm, and the thinnest resolvable tubules are few hundreds of microns in diameter.

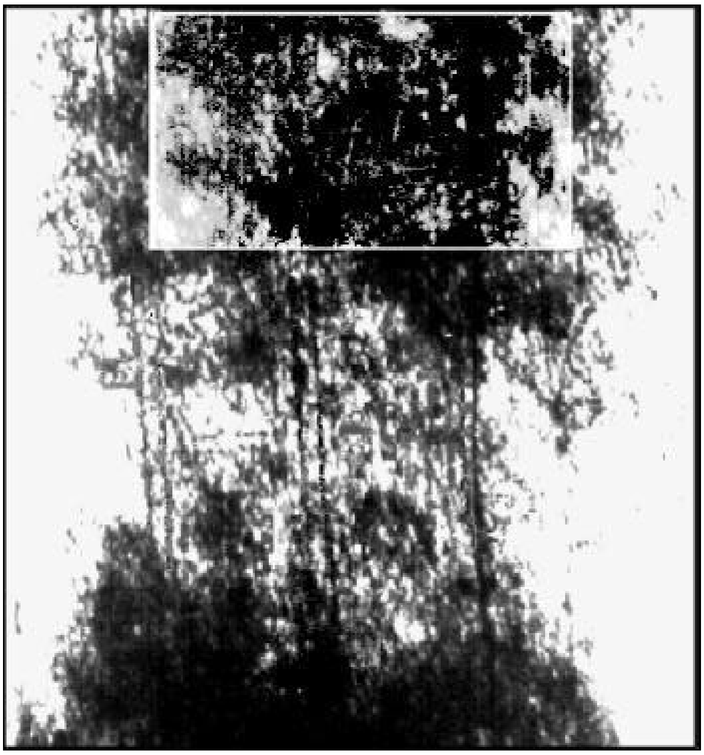

Fig. 3. The neck of a Z-pinch (major conditions are similar to those of Fig. 1). Negative, t = 0 ns, time exposure 2 ns; image height 1.65 cm. Diameter d of vertical tubules is ~0.3 mm, while for thinner tubules of various directions, including horizontal ones, d ~ 0.1-0.2 mm. Diameter of coaxial tubules seen, e.g., in the right hand side, is ~1 mm. The picture illustrates the presence of a network built up by the tubular rigid-body filaments which may be hidden in the ambient plasma but appear to be stripped by the magnetic field when it pushes the plasma out of the Z-pinch s neck (it is such event that leads to a singularity of total current through the Z-pinch).

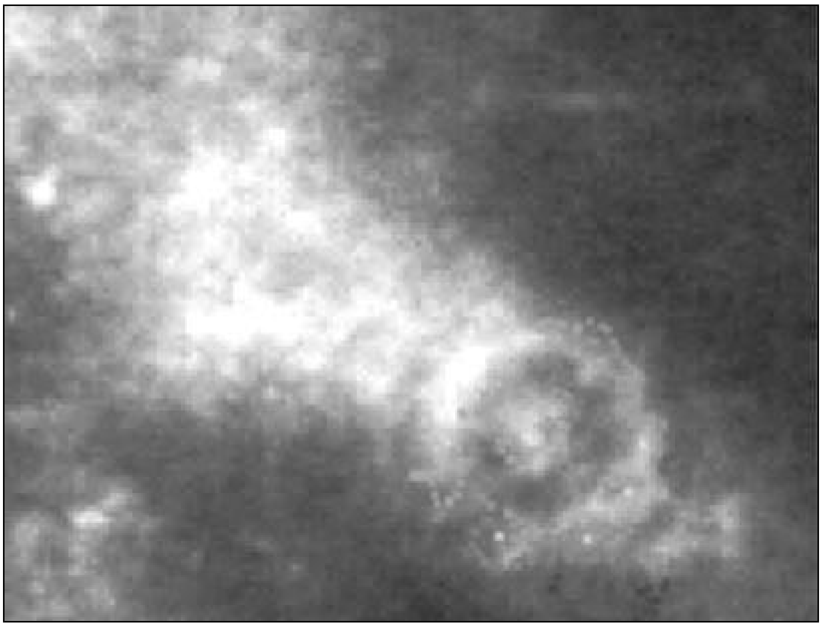

Fig. 4. Typical tubular formation (of diameter ~ 0.5 mm) directed nearly perpendicular to the curvilinear filamentary current sheath at the implosion phase of the discharge in the plasma focus facility [6] of the Filippov type (for experimental conditions see also [7]). The picture is a shadowgram (positive) taken from the facility s top (laser pulse of 2ns duration passes up through a hole in the mushroom anode, i.e. the picture shows radial projection of the tubular formation). Image width 2.5 mm.

An analysis of measurements of HF electric fields in tokamak T-10, both inside and outside plasma column, revealed [5] their reasonable agreement with the predictions based on [4].

An extension of the wild cable approach [5] from tokamaks to Z-pinches and plasma foci gives the following result: at conditions of Figs. 1-4, a straight block of few hundreds of microns in diameter may work as a wild cable. In particular, the values of HF electric fields observed [8] in the peripheral plasma of the Z-pinch shown in Figs. 1-3, are sufficient to protect the skeletons from the hot plasma (see Fig. 5 and also paper P2.028 for more detail).

Therefore, experimental data, and an analysis of these data from the viewpoint [5], suggest the possibility of a direct (non-diffusive, nonlocal) transport of EM energy toward plasma core -- not only on the stage of the formation of a precursor on the axis of the facility but at the quasi-steady-state stage (stagnation) as well.

We highly appreciate authors [6] for presenting the original data for Fig.4.

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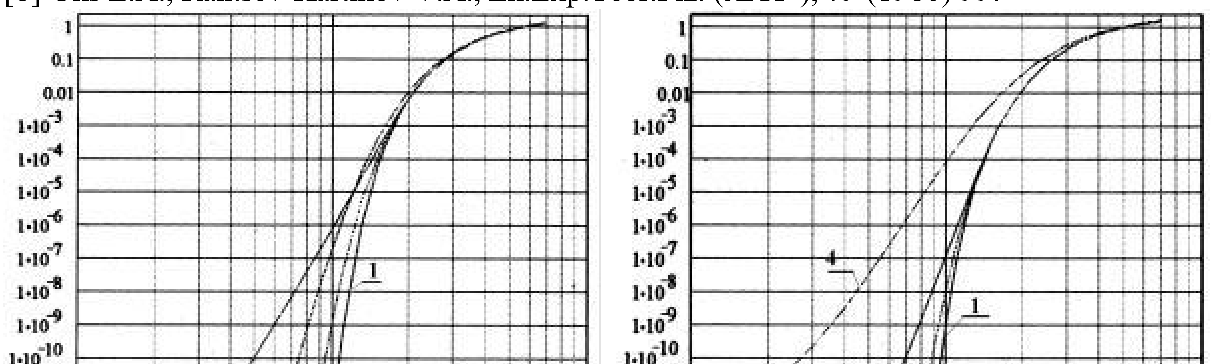

Fig. 5. Electron (curve 1) and ion (2) densities vs. radial coordinate (in mm) in a coaxial «wild cable», as calculated from the Poisson equation for a quasi-hydrodynamics of a plasma in a HF electric field ($\omega=\pi c/L$, L is cable s length [5], L =1 mm), for electron HF oscillation radius neglected ($R_{osc} = 0$); density in the limit of plasma quasi-neutrality (curve 3); density (1) when shifted inward by the local value of R_{osc}, gives curve (4). On the left, peripheral plasma with background Ne0 $=10^{15}$ cm^{-3} , Te = 10 eV , cable s voltage U = 10 kV; on the right, Z-pinch core with Ne0 = 10^{18} cm^{-3}, Te = 100 eV, U = 30 kV.