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Self-Assembling of Filaments and Closing the Electric Circuit in a Random Ensemble of a Strongly Magnetized Dust

A.B. Kukushkin,[1] N.L. Marusov,[1] P.V. Minashin,[1,2] V.S. Neverov[1,2]

[1]*NFI RRC "Kurchatov Institute", Moscow 123182, Russia*
[2]*Moscow Engineering Physics Institute, Moscow 115409, Russia*

1. Introduction. We study the possibility of self-assembling of filamentary structures from a magnetized electroconductive dust, which may close the electric circuit via self-closing of filaments in an electrodeless discharge in an external magnetic field (e.g., in a toroidal system). We use the 3-D numerical model [1(a)] for a many body system of strongly magnetized thin rods (i.e. 1D static magnetic dipoles). Each block possesses the longitudinal electric conductivity and the electric charge, statically screened with its own plasma sheath. Numerical modeling of $\sim 10^2$-10^3 such dipoles has shown [1(b),2] the possibility of electrodynamic self-assembling of a tubular skeletal structure from an ensemble of initially-linear dust filaments, linked to biased electrodes. To substantiate such initial conditions, the possibility of self-assembling of quasi-linear filaments (and closing of the electric circuit) was studied [3] for an initially random ensemble of basic blocks in the magnetic field of a plasma filament with internal longitudinal magnetic field (i.e., nearly force-free internal magnetic configuration).

Here we analyze the problem of filament self-assembling in the presence of quasi-homogeneous external magnetic field. The process under consideration models the initial stage of skeletal structure formation in the laboratory electric discharges in toroidal magnetic systems.

2. Filament self-assembling in a random ensemble of basic blocks. Numerical modeling of evolution of a random ensemble of basic blocks with above-mentioned properties is focused at the influence of quasi-homogenous background magnetic field on self-assembling of filaments from randomly situated dust particles, including a comparison with the case of self-assembling in the presence of magnetic field of a plasma electric current filament [3]. The closing of the electric circuit ("short-circuiting") is defined as the emergence of, at least, a single filament whose ends lie closer than *L/2*, where *L* is dipole's length, to the edge z-planes of the initial box (see Fig 1, left). The filament is defined as a chain of blocks whose closest tips permanently lie within the distance *2D* (where *D=0.03 L* is diameter a thin rod), which describes the characteristic radius of the potential well of the model pair interaction of the tips (compilation of magnetic attraction and elastic repulsion of the tips, see Fig. 1 in [1(a)]). The results of our analysis are illustrated with Figs. 1-4, where time and magnetic field are expressed, respectively, in the units of t_0 and B_0:

$$t_0 = \frac{\sqrt{mL^3}}{Z_{M0}e} \sim \left(\frac{L}{10\,nm}\right)^2 \sqrt{\frac{D_{CNT}}{1nm}}\,\frac{1}{Z_{M0}}(n\sec), \quad B_0 = \frac{Z_{M0}e}{L^2} \sim Z_{M0}\left(\frac{10\,nm}{L}\right)^2 5\cdot 10^{-2}\,(T)$$

where *2m* and *L* are the mass and the length of each basic block; $Z_M = \Phi/4\pi e$ is the effective magnetic charge (in the units of electron charge *e*) on the tip of 1-D magnetic dipole; Φ is magnetic flux, trapped in the 1-D dipole; $Z_{M0} = 1$, that is close to the average charge (t_0 is also estimated for particular case of single walled carbon nanotube of diameter D_{CNT}).

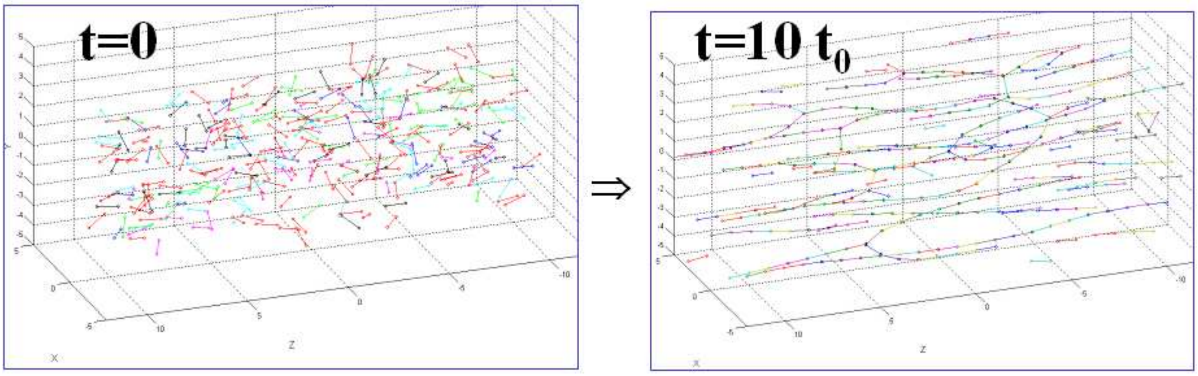

Fig. 1. Initial position (left) and that at time t ~ 10 t_0 (right) for the ensemble of 300 blocks, randomly situated at t=0 in the box 12×12×20 (in the units of dipole's length *L*) in external magnetic field $B=Bz=3B_0$. Magnetic charge Z_M is random in the interval {0.67,2}, electric charges $Z_{ei}=Z_{Mi}$ (i=1÷300), electrical screening radius $r_D=L$, brake coefficients for tip's collision, $(k_{br})_{dd}=100$, and for brake in the ambient medium, $(k_{br})_{dm}=3$ (see [1(a)]).

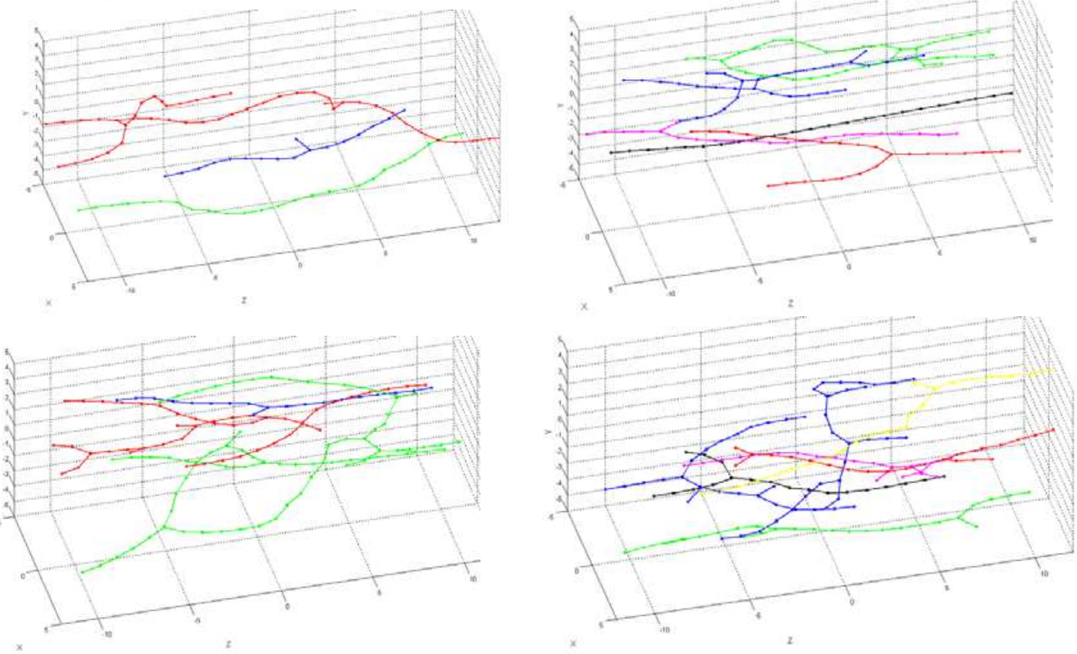

Fig. 2. Four typical examples of the *longest* filaments at time t ~ 10 t_0 in the ensembles with different random initial positions at t=0. Other parameters are similar to those for Fig 1.

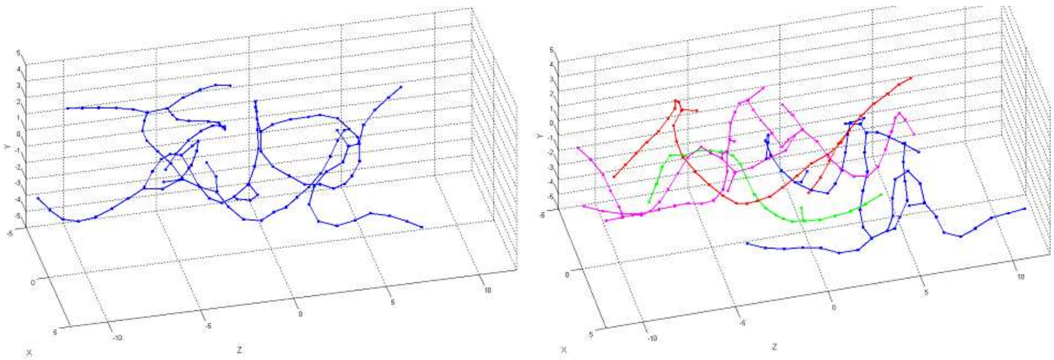

Fig. 3. The same as in Fig. 2 but for $Bz=B_0$ and the presence of magnetic field of (Z-directed, with center at X=Y=0) plasma electric current filament of radius $R_{pl.}= 1.5L$, with total longitudinal electric current $J_{zPlas}=1.5cZ_{M0}e/L$. The cases of *random* distribution of magnetic charges (left) and *quantized*, Z_M=1 and Z_M=2 with ratio 2/1, (right) with the same average value $\langle Z_M \rangle$=4/3, are presented.

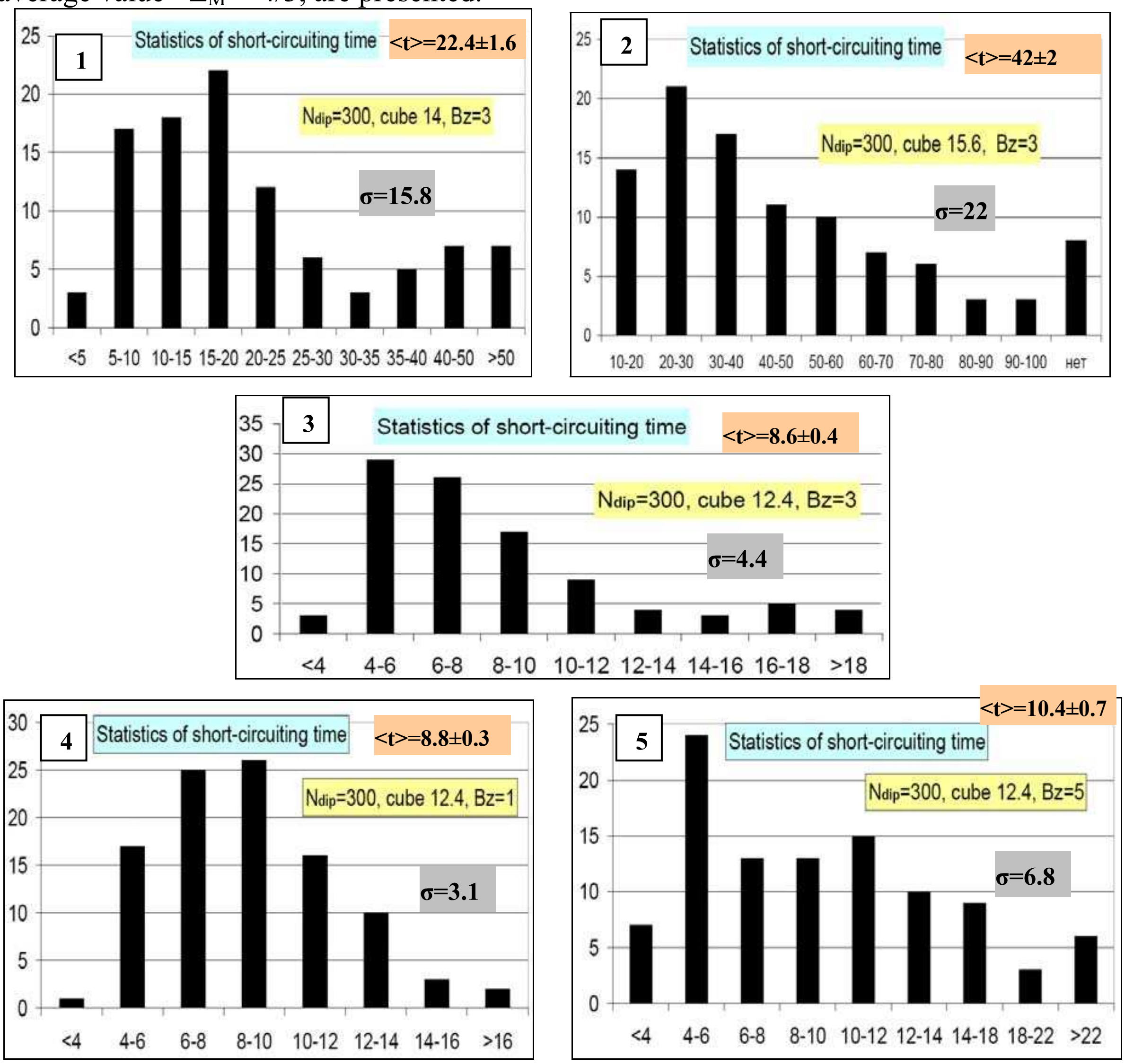

Fig. 4. Statistics of the time needed for closing the electric circuit ("short-circuiting") with at least a single filament for conditions of Fig. 1, but another geometry of initial box (a cube of the size 12.4, 14, and 15.6). For the size 12.4, a scan over $B_z/B_0=1, 3, 5$ is presented. Here $\langle t \rangle$ is the average time of short-circuiting, with confidence probability 0.7, σ is root-mean-

square deviation. Everywhere, 100 computations were done up to time 100 t_0. The last pockets in the histograms 1,2,4,5 are wider than initial ones. Local maxima in the pockets «35-40» and «16-18» in histograms 1,2,4,5 are caused by statistical error.

It appears that alignment of the magnetized blocks along a static magnetic field is favorable for closing of electric circuit, if it suppresses the trend towards isotropic networking of self-assembled filaments and thus shortens the way towards short-circuiting. This conclusion, obvious for comparison with the case of no external magnetic field, is illustrated with the impact of azimuthal magnetic field of a plasma filament (cf. Fig. 2 vs. Fig. 3).

The timescale of short-circuiting strongly depends on the initial density of blocks, $n_{dip}^{(0)}$ (cf. Fig. 4, histograms 1-3). For $n_{dip}^{(0)} \approx 0.16\ L^{-3}$ (histograms 3-5), it is comparable with that for subsequent stages of self-assembling [1(b),2] ($t \sim 10\ t_0$), whereas for twice lower $n_{dip}^{(0)}$ this time increases by a factor of 4-5 (histograms 1,2).

Dependence of short-circuiting time on the strength of external magnetic field, *Bz*, appears to be appreciably weaker (cf. Fig. 4, histograms 3-5). Nevertheless, it is possible to evaluate the optimal value of *Bz* (cf. Fig. 4, histograms 3,4).

For a certain initial density of blocks, the dependence of short-circuiting time on the distance, ΔZ, between two virtual planes, connectable with an electroconductive filament, tends, with increasing ΔZ, to a certain limit.

3. Conclusions. The results suggest probable positive role of external magnetic field for electrodynamic self-assembling of macroscopic skeletal structures, identified in a broad range of length scales in laboratory electric discharges and space [4], from the blocks with above-mentioned electrodynamic properties (presumably, carbon nanotubes and similar nanostructures). This positive impact seems to be especially strong in the electric discharges in a strong toroidal magnetic field.

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