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A Model of Skeletal Structuring of Magnetized Dust in a Plasma Filament in Laboratory and Space

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1. Introduction. Fractal condensed matter composed of magnetized nanotubular dust was suggested [1(a)] to form a skeleton of filamentary structures observed in laboratory electric discharges and space, for explaining the unexpected longevity of these filaments and their unexpected (sometimes transverse) direction with respect to that of main electric current. A simple 3-D numerical model [2(a)] of many-body system of magnetized, electrically conducting thin rods (1-D magnetic dipoles, in particular, magnetized nanotubular dust [1]) managed to describe electrodynamic (magnetic and electric) self-assembling of coaxial tubular skeleton in a system of magnetic dipoles, which are initially arranged as linear electric current filaments with a fraction of the dipoles with uncompensated magnetic flux [2(b-d)]. Here, we numerically model the behavior of a strongly magnetized dust within a filament of plasma electric current. This is aimed at (i) partial substantiation of plausibility of initial conditions for modeling [2(b-d)] (via modeling the trend towards self-assembling of a quasi-linear filament in a random ensemble of dipoles) and (ii) demonstration of possibility of self-assembling of quasi-planar skeletal structuring during the transient phenomena in laboratory electric discharges and space (e.g., after detachment of dust filaments from mother electrodes).

2. Self-assembling of quasi-linear filament in a random ensemble of dipoles. Consider an ensemble of randomly-oriented magnetized dust particles (Figs. 1(a,c)), with each particle being [2(a)] a static lengthy (i.e. 1D) magnetic dipoles with the longitudinal electric conductivity and the static electric charge, screened with dipole's own plasma sheath. This ensemble is subjected to external magnetic field produced by electric current filament of radius R_{pl} . Longitudinal and azimuthal current within the filament are assumed to have uniform current density (such distribution roughly models the cylindrical force-free magnetic field configuration which is believed to occur in "magnetic flux ropes" [3] in space and laboratory). Such initial conditions may occur, e.g., during electric breakdown phenomena when a plasma electric current appears in a medium with randomly distributed, dispersed nanotubular dust.

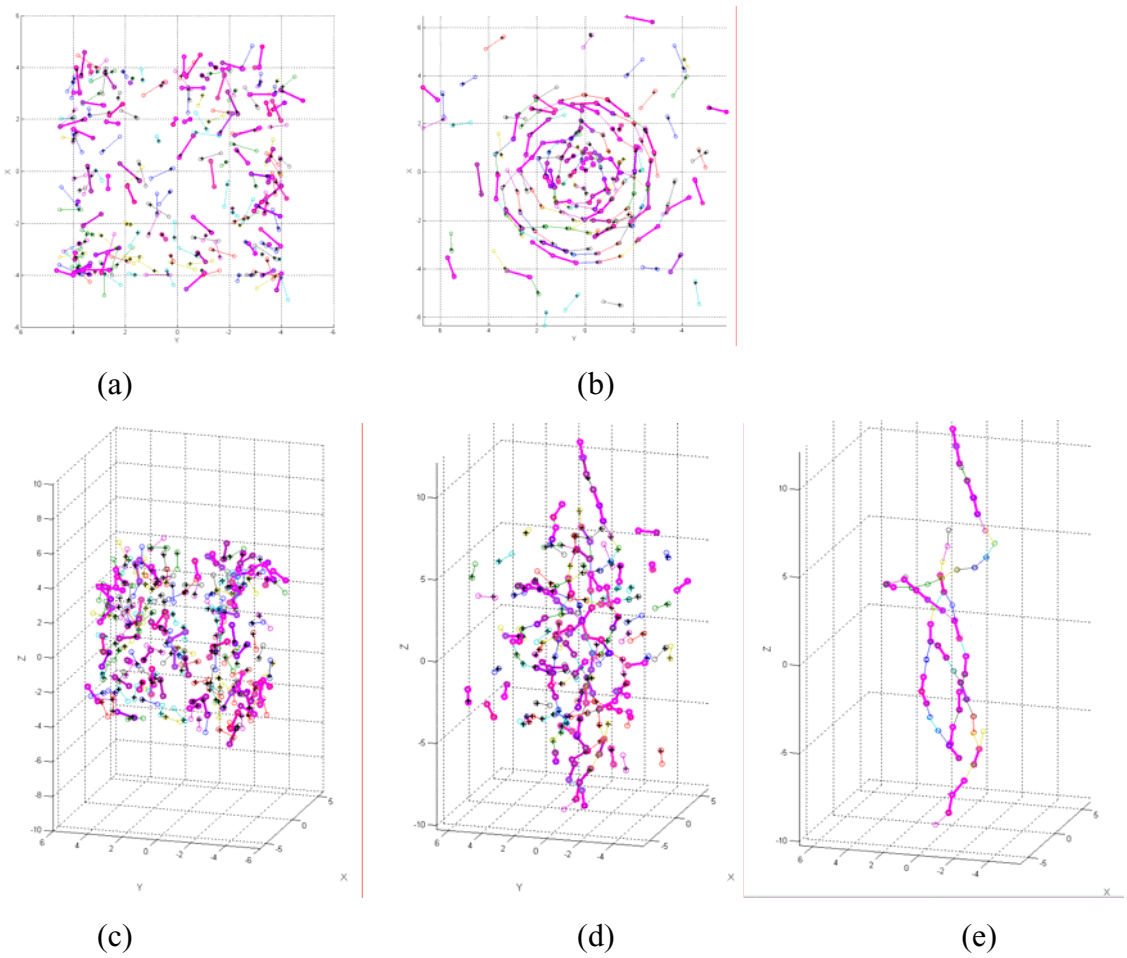

Fig. 1. Top-on (a) and 3-D views (c) on initial position of ensemble of randomly-oriented 1-D dipoles. Total number of blocks N_{dip} = 250, magnetic charge $Z_M=2Z_{M0}$ (thick magenta blocks) and $Z_M=Z_{M0}$ (others), fraction of magnetically double-charged blocks f_{2ZM0}= 1/3, electric charge $Z=Z_M$, screening length r_D=1. Space coordinates are given in the units of dipole's length L. Top-on (b) and 3-D view (d) views at time $t \sim 15(mL^3)^{1/2}(Z_{M0}e)^{-1}$ for parameters [2(a)]: brake coefficients for tip's collision, $(k_{br})_{dd}$ =100, brake in the ambient medium, $(k_{br})_{dm}$ =3, radius of (Z-directed, with center at X=Y=0) electric current filament $R_{pl.}$= $4L$, total longitudinal electric current $J_{zPlas}=10cZ_{M0}e/L$, longitudinal magnetic field on filament's axis $B_{zPlas}(Z=0)=5Z_{M0}e/L^2$. A single-connected filamentary structure (e), with largest number of blocks (~60), in the ensemble in figure (d).

The evolution of such a system is governed by (i) alignment of dipoles along local magnetic field, that favors formation of linear dust filaments of helical form, (ii) attraction of these filaments to plasma electric current axis due to the dipoles with uncompensated magnetic flux and the edge dipoles, (iii) formation of a structure stretched along filament's axis, due to the counter action of the above magnetic attraction and the close Coulomb repulsion of dipoles (Figs. 1(b,c)). This may lead to formation of single-connected quasi-linear filamentary structure(s), stretched along the axis of plasma electric current filament of a force-free type (e.g., at a distance twice longer than the height of initial ensemble of dipoles, Fig, 1(e)). This modeling shows the possibility of the buildup of an electrically

conductive structure, which may close the electric circuit inside already existing filament of plasma electric current, either between the biased electrodes or inside the current loop.

3. Quasi-planar structuring of currentless linear dust filaments. Another interesting example of possible interplay of the plasma current and the magnetized dust is related to the impact of magnetic field of plasma electric current filament on a bunch of initially linear filaments composed of dust particles with properties [2(a)]. Such initial conditions assume formation of (quasi-)linear dust filaments (e.g., by the mechanism of Sec.2) prior to appearance of a stronger and thicker filament of plasma electric current which we assume here to be purely longitudinal. Under these conditions the processes, listed of Sec. 2, may give quite different final structuring. The plasma's magnetic field again tends to orient along the field's direction the dipoles with uncompensated magnetic flux and the edge dipoles. This results, however, in another type of reduction of spatial dimensionality: from initial quasi-homogeneous 3D system to a quasi-planar one (Fig. 2) [4]. Subsequent magnetic networking (due to a fraction of dipoles with uncompensated magnetic flux), regulated by close Coulomb repulsion of dipoles, forms a quasi-planar skeletal structure.

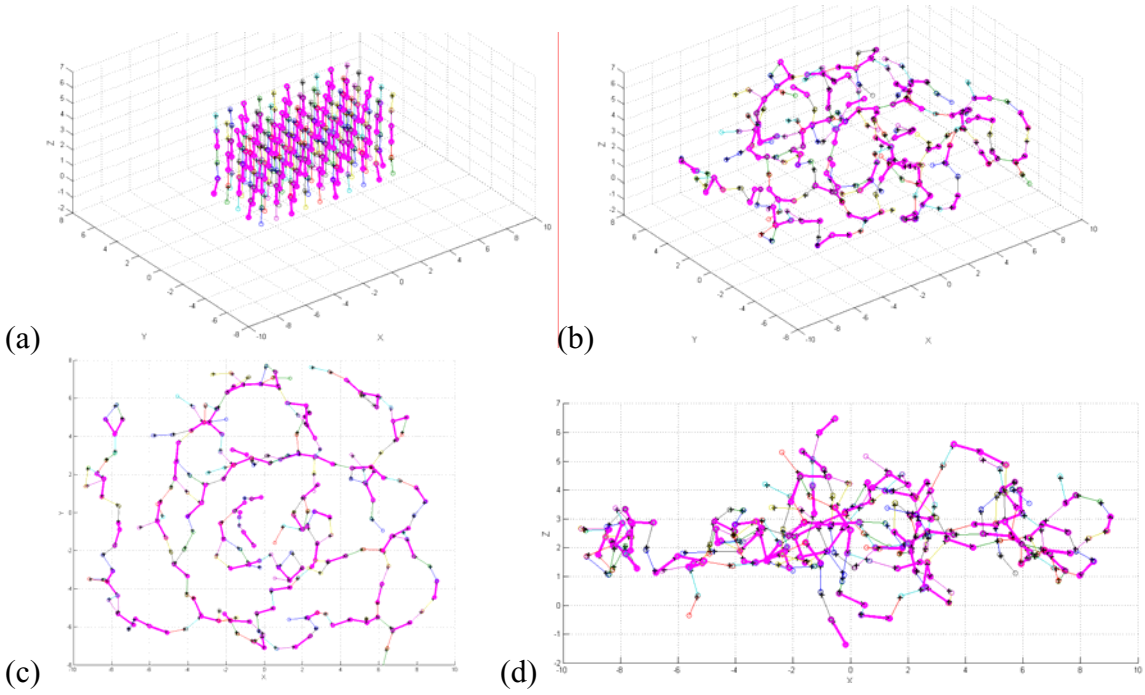

Fig. 2. 3-D view (a) of the initial position of a bunch of filaments composed of 1-D magnetic dipoles for total number of blocks N_{dip} = 250, number of blocks in filament = 5, number of filaments = 50, magnetic charge $Z_M=2Z_{M0}$ (thick magenta blocks) and $Z_M=Z_{M0}$ (others), fraction of magnetically double-charged blocks f_{2ZM0}= 1/3, electric charge Z= Z_{M0}, screening length r_D=1. Space coordinates are given in the units of dipole's length *L*. The 3-D (b), top-on (c) and side-on (d) views at the quasi-stationary stage (t ~ 20 $(mL^3)^{1/2}(Z_{M0}e)^{-1}$) for $(k_{br})_{dd}$ =100, $(k_{br})_{dm}$ =3, R_{pl}.= 6*L*, $J_{zPlas}=2.5cZ_{M0}e/L$, B_{zPlas}=0.

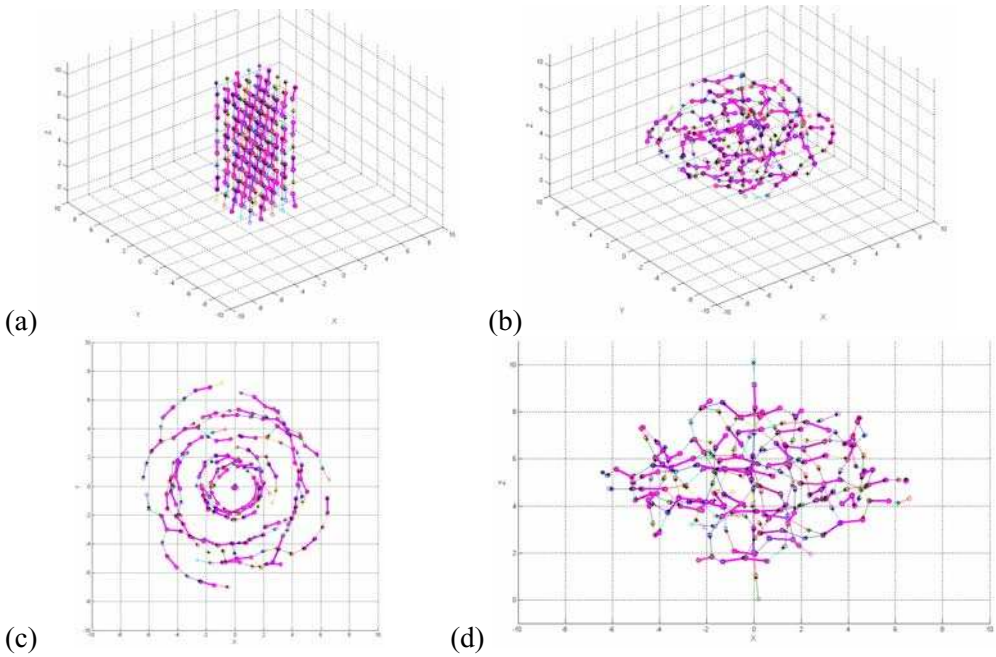

Fig. 3. Pictures similar to Fig. 2, for the same parameters, but number of blocks in filament = 10, number of filaments = 25, $R_{pl.} = 4L$, $J_{zPlas} = 5cZ_{M0}e/L$.

4. Conclusion. The results demonstrate possible mechanisms of the impact of external magnetic field, specifically that of plasma electric current, on restructuring and "magnetic threading" of magnetized dust, and append the picture [2(c,d)] of self-assembling of coaxial tubular skeleton between the biased electrodes with the complementary picture of skeletal self-assembling in randomly distributed ensemble of magnetized dust particles and in a system of currentless (detached from electrodes) linear dust filaments. In particular, it follows that planarity of structuring may be supported (and/or caused) by magnetized dust filaments in electric current-carrying plasmas. Numerical models [2,4] give a background for demonstrating the possibility of self-assembling of *macroscopic* skeletal structures, identified in a broad range of length scales in laboratory electric discharges and space [1(b)], from the blocks with electrodynamic properties [2(a)].

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