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Magnetic Dynamo and a Trend Towards Fractality in a Random Ensemble of Magnetized Electroconductive Nanodust

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1. Introduction. We present the results of numerical modeling of electrodynamic aggregation in a random ensemble of magnetized nanodust taken as a many body system of strongly magnetized thin rods (i.e., one-dimensional static magnetic dipoles), which possess electric conductivity and static electric charge, screened with its own static plasma sheath. The self-assembling of quasi-linear filaments from an ensemble of randomly situated basic blocks and the electric short-circuiting between biased electrodes were shown [1] to be supported by the alignment of blocks in an external static magnetic field. Statistical analysis of short-circuiting time allows tracing the dynamic percolation of electric conductivity and shows a substantial decrease of percolation threshold as compared, e.g., with the observed percolation of carbon nanotubes in liquids and polymer composites.

Here, modeling of short-circuiting stage of evolution is continued with tracing the dynamics of pinching and networking of electric current filaments. A trend towards a fractal skeletal structuring (namely, repeat of original basic block at a larger length scale) is studied in the view of generation of a bigger magnetic dipole. The interplay of all the magnetic and electric mechanisms of filaments' assembling and networking is analyzed, and a comparison of magnetic dynamo with that in scenarios [2] of skeletal structuring in a system of linear filaments composed from such blocks is made.

2. From chaotic magnetized electroconductive nanodust to pinching and networking of electric current filaments. Here we present the results of a continuous modeling of aggregation in a random ensemble of nanoblocks between the biased electrodes. This includes the short-circuiting stage of evolution and traces the dynamics of pinching and networking of electric current filaments to show the interplay of all the magnetic and electric mechanisms of filaments' networking, including the dynamo effect. The computation is carried out with the parallel code SELFAS-2. It is based on the formalism of the model [3] and extends this model (and respective calculations, see [2] and refs. therein) to allow for (i) dynamic coupling of filaments to electrodes during short-circuiting (the interaction with the electrodes is modeled by a 1D potential well for effective magnetic charges on the tips of the blocks), (ii) electric current dynamics after short-circuiting for a given voltage U and electric resistance R_0 of each blocks (the inductance of filaments is ignored). The results of our analysis are illustrated with Figs. 1-3, where time and magnetic field are expressed, respectively, in units of t_0 and B_0:

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

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 (Z_{M0} is close to average magnetic charge); Φ is magnetic flux, trapped in the 1-D dipole, that is close to the average effective magnetic charge. In Eq.(1), for t_0 we give also its numerical estimate for particular case of single-walled carbon nanotube of diameter D_{CNT} .

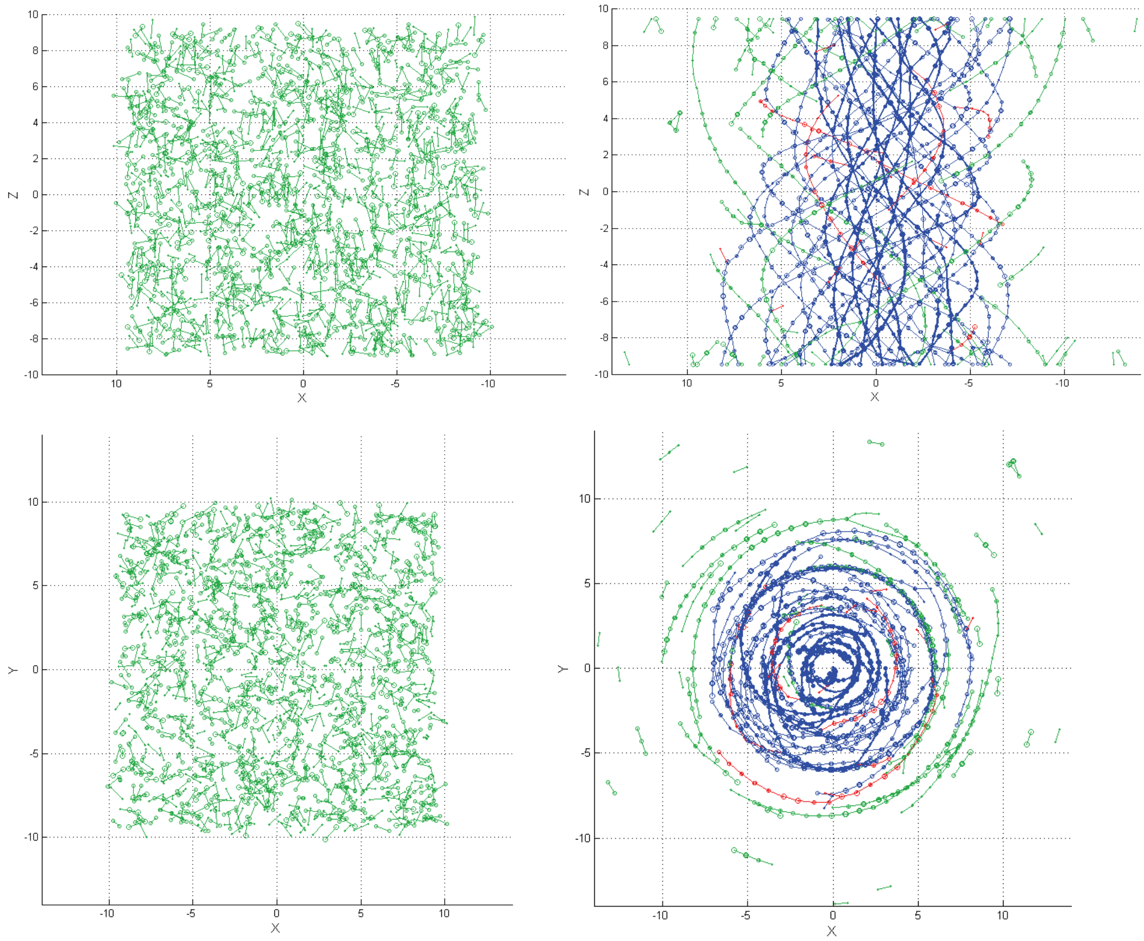

Fig. 1. Side-on (top) and top view (bottom) of the ensemble of basic blocks at time t=0 (left) and t=300 (right) (in units of t_0, Eq. (1)). Short-circuited filaments are shown with blue color, while the dead ends within the network of short-circuited filaments are shown with red. Block's number Ndip = 1200, block's inverse aspect ratio D/L = 0.06, initial space dimensions = [(-9.2,9.2);(-9.2,9.2);(-9.45,9.45)] (in units of block's length *L*), electric screening radius $r_D = L$, $F_{0JJ} = 0.25$ (Eq. (2)), brake coefficients for tip-tip collision, $K_{brake} = 100$, and for brake in a ambient medium, $M_{brake} = 1.5$, circuit parameter $\delta_{J0} = 2.1$. Homogeneous external magnetic field B_{ext}= 1.5 B_0 and a plasma electric current filament (with center at x=y=0 and $R_{plas} = 6L$) are Z-directed, total longitudinal electric current through plasma filament $J_{zPlas}=7.5\,J_{ZM}$.

The force of electric current interaction for blocks at a distance $\boldsymbol{r}_{ij}$ (expressed, similarly to [3], in units of attraction of effective magnetic monopoles on the tips at a distance of block's length L, with the latter taken a constant for all the blocks) is expressed in terms of F_{0JJ} [3]:

$$\vec{F}_{Ampere} = \frac{F_{0JJ} I_i I_j \, \vec{L}_i \times (\vec{L}_j \times \vec{r}_{ij})}{r_{ij}^3}, \quad F_{0JJ} = \left(\frac{J_0}{J_{ZM}}\right)^2, \quad J_{ZM} = \frac{cZ_{M0}e}{L} = \left(\frac{10nm}{L}\right) Z_{M0} \, 5 \cdot 10^{-3} A, \quad (1)$$

where the current I_i in the i-th block is expressed in units of the current J_0 and is defined by the electric circuit equations and the parameter $\delta_{J0} = U\,L/(R_0 J_0 \Delta Z)$, where ΔZ is the distance between electrodes.

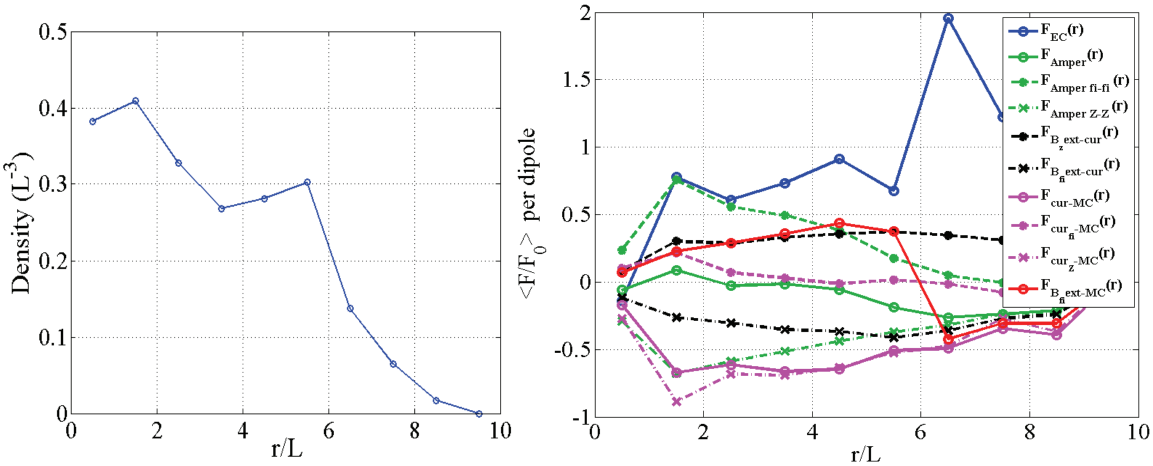

Fig. 2. Radial profiles at time t=300 t_0 for the conditions of Fig. 1. **Left**: density of basic blocks (averaged over longitudinal direction and azimuthal angle). **Right**: radial forces (averaged over longitudinal direction and azimuthal angle) acting at a basic block ($F_0=e^2 Z_M^2/L^2$). EC – electric repulsion, Ampere – interaction of electric currents through filaments composed of basic blocks, “Ampere fi-fi” (“Ampere Z-Z”) – interaction of azimuthal (longitudinal) components of these electric currents, “$B_z$ext-cur” (“B_{fi}ext-cur”) – interaction of these current with external longitudinal (azimuthal) magnetic field, “cur-MC” (“cur_{fi}-MC”, “cur_Z-MC”) – interaction of magnetic dipole with magnetic field of electric current (its azimuthal, longitudinal components) through the filaments composed of basic blocks, “B_{fi}ext-MC” – interaction of magnetic dipole with azimuthal magnetic field of plasma filament.

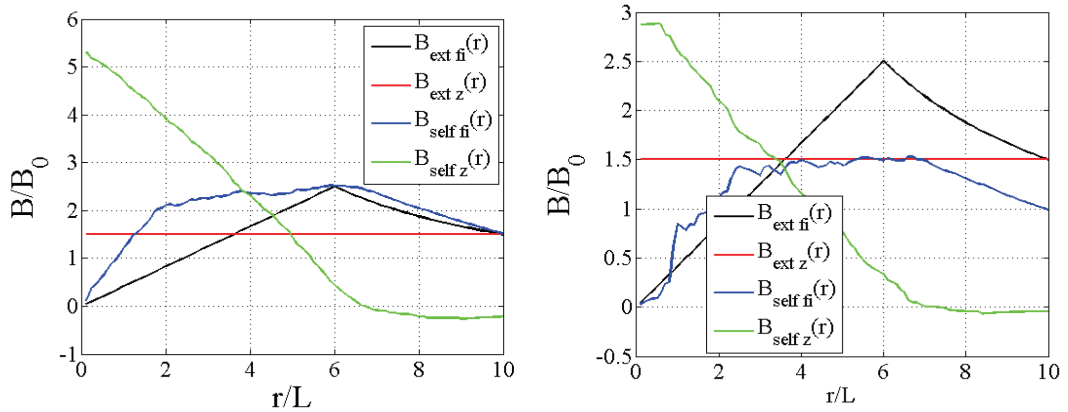

Fig. 3. Radial profile of magnetic field components, averaged over azimuthal angle, at time t=300 t_0 for the conditions of Fig. 1, in the center of the column, z=0, (left) and in the edge, z=9, (right); “ext fi” – azimuthal magnetic field of z-directed plasma filament, “ext z” - external z-directed magnetic field, “self fi” - azimuthal magnetic field of electric current through filaments composed of basic blocks, “self z” – z component of these currents.

Figure 3 gives an evidence for generation of longitudinal magnetic field and, respectively, of a bigger magnetic dipole. This result is fully predetermined by the lengthyness of magnetized electroconductive nanoparticles: the alignment of lengthy magnetized blocks inside the filaments along magnetic field of the current through these filaments self-consistently produces internal longitudinal magnetic field like in a solenoid.

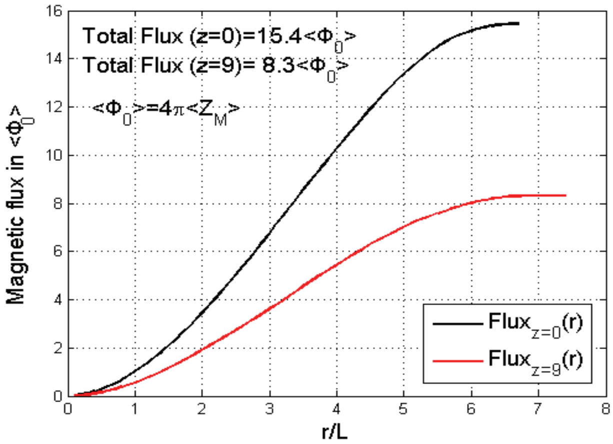

Figure4. Magnetic flux produced in a system of Fig. 1. This result extends previous evidence for such a dynamo effect found in the modeling of a bunch of initially linear filaments, "artificially" composed of basic blocks and coupled to the biased electrodes (see Fig. 5 in [4]), to the case of a modeling which starts from a random ensemble of dispersed basic blocks. The value of produced magnetic flux (Fig. 4) appears to be close to that in the case [4] ($\Phi \sim 10\ \Phi_0$ for 500 basic blocks, each of flux Φ_0).

3. Conclusions. A continuous numerical modeling of various stages of aggregation in a random ensemble of magnetized electroconductive blocks between the biased electrodes is carried out with a parallel numerical code. A trend towards a fractal skeletal structuring (namely, repeat of original basic block at a larger length scale) is illustrated with an evidence for generation of a bigger magnetic dipole composed of basic blocks. Such a magnetic dynamo is a transparent consequence of the lengthyness of magnetized electroconductive nanodust particles.

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REFERENCES

[1] Kukushkin A.B., Marusov N.L., Minashin P.V., Neverov V.S. Proc. 35th EPS Conf. Plasma Phys. (Greece, 2008), P-5.134.

[2] Kukushkin A.B., Cherepanov K.V., Phys. Lett. A **364**, 335-342 (2007); Kukushkin A.B., IEEE Trans. Plasma Sci. **35**, 771-777 (2007).

[3] Kukushkin A.B., Cherepanov K.V., Preprint ArXiv: physics/0512234 (2005).

[4] Kukushkin A.B., Cherepanov K.V., Proc. 34th EPS Conference on Plasma Phys. (Warsaw, 2007), ECA vol. 31F, O-2.015.