Three Dimensional Dynamics of Ferromagnetic Swimmer

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There is growing interest in creation of bioinspired microdevices to carry out different functions in biotechnology and medicine.

We are developing a new route for the creation of such devices, which are powered by the AC magnetic field. They are created by linking with 1000 kb long biotinized DNA fragments commercially available functionalized core-shell ferromagnetic particles. Magnetization curve of the diluted sample of the ferromagnetic particles shows hysteresis with the coercitive force $H_c = 550\ Oe$ and specific remnant magnetization 3 emu/g.

Filaments of the linked ferromagnetic beads in magnetic fields $H < H_c$ are magnetized along their axis and orient in the direction of the magnetic field. Abrupt inversion of the direction of the magnetic field leads to the formation of the loop and its symmetry breaking. Experimentally and numerically it is shown that the loop is unstable with respect to the three dimensional perturbations and after some transition period which depends on the magnitude of the initial perturbation relaxes to the straight configuration. In the unidirectional AC field the filament self-propels in the plane of its initial curvature perpendicularly to the AC field. Its locomotion consists in periodic sequence of power and return strokes similarly to some biflagellate algae. Dependance of the displacement on time for four periods is shown in Figure (left). It is possible to notice period doubling – the same return strokes repeat after two periods of AC field. The motion of the filament in the plane is unstable with respect to the three dimensional perturbations. This instability is characterized by the calculation of the writhe number. For the initial inclination angle of the plane of curvature to the field 10^{-4} and $Cm = 72$ it is shown in Figure (right). It shows that after transition period which depends on the frequency of the AC field the writhe number becomes equal to zero. This corresponds to the transition from the oscillating U-like shape to the oscillating S-like shape oriented perpendicularly to the AC field. Unusual orientation of the ferromagnetic filament perpendicularly to the AC field is caused by its flexibility – neutral with respect to the AC field perpendicular orientation due to the deformation has lower mean energy per period than the straight configuration along the AC field.