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Synchronization of rotating flagella by hydrodynamic interactions

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Rotating bacterical flagella form bundles, which means that their rotations have to be synchronized. The aim of our study [1] is to show that hydrodynamic interactions, i.e., interactions mediated by the flow field the helical flagella create, can be at the origin of such a synchronization.

We consider two stiff helices that are modeled by rigidly connected beads, neglecting any elastic deformations in a first approach [1]. The helices are driven by constant and equal torques. They are fixed in space by anchoring their terminal beads in harmonic traps so that they can jiggle around. We observe that, for finite trap strength, hydrodynamic interactions, treated in the low-Reynolds-number regime, do indeed synchronize the helix rotations to a phase difference zero. The speed of phase synchronization decreases with increasing trap stiffness and becomes zero in infinitely stiff traps. So strictly parallel helices do not synchronize. This limit is consistent with recent work based on slender-body theory [2]. We furhermore show that phase synchronization is stable against fluctuations in the torques driving the helices.

Our results clearly indicate that some kind of flexibility is essential to allow for phase synchronization. In reality, this flexibility might have its origin in the proximal hook connecting the flagellum to the rotatory motor or in elastic deformations of the rotating flagella. Indeed, when we extend our model by implementing the elasticity of a helical worm-like chain, synchronization occurs much faster even for relatively stiff helices.

[1] M. Reichert and H. Stark, Eur. Phys. J. E **17**, 493 (2005).

[2] M.J. Kim and T.R. Powers, Phys. Rev. E **69**, 061910 (2004).