MAGNETIC MANIPULATION OF BACTERIA IN MICROFLUIDICS

Marc P. Pichel[1], Tijmen A. G. Hageman[1], Matthias O. Altmeyer[2], Leon Abelmann[1,2] and Andreas Manz[1]

[1]KIST Europe, Germany, and [2]University of Twente, The Netherlands

ABSTRACT

We measured for the first time the U-turn trajectory of individual magneto-tactic bacteria (MTB) under reversal of the magnetic field, as a function of the field strength. The measurement was performed using shallow 5 micrometer deep microfluidic channels and a setup which allowed for magnetic fields with rapid alternating directions at varying magnitudes up to 60 mT.

KEYWORDS: magnetotactic bacteria, microfluidics, dynamic model, u-turn, magnetic field

INTRODUCTION

Several groups have worked on dynamic models for control of MTB, using estimates of the magnetic dipole moment determined from U-turn trajectories as a result of field reversal [1,2]. Based on these dynamic models, attempts have been made at closed-loop control. These experiments are frustrated by overheating of the electromagnets [3]. Probably because of this, no reports have been made on the response of a single MTB to magnetic fields with field magnitudes up to saturation. This information is important to understand the limitations of the influence which magnetic fields can exert on MTB, and subsequently optimization of control.

According to [1,2] the ratio of bacteria velocity v over radius of curvature R of a U-turn is proportional to the field strength B,

$$\frac{v}{R} = \left(\frac{2m}{\alpha\pi}\right) B,$$

where α is the shape factor for viscous drag and m the magnetic dipole moment of the MTB (Figure 1). This model is an approximation, only valid for low values of B.

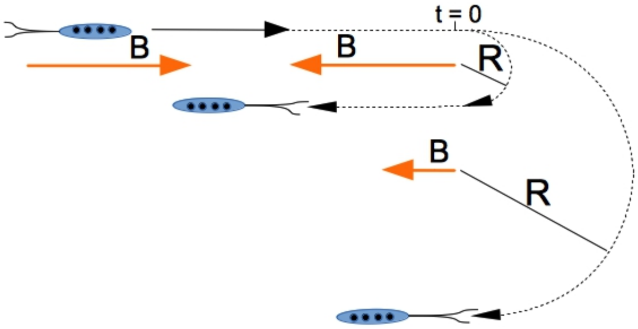

Figure 1: The expected radius of the trajectory that the magneto-tactic bacteria take under reversal of the magnetic field (at t=0) decreases with increasing field strength.

EXPERIMENTAL

To validate this approximation, a microfluidic chip was designed such that the MTB are confined to the 2D-plane for observation, with a limited depth of 5 micrometer to keep MTB within the field of focus at high optical magnifications.

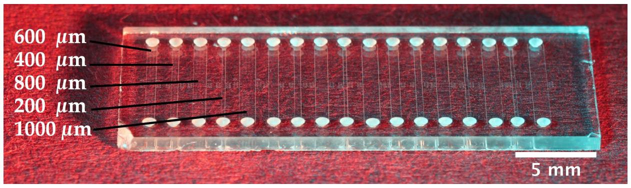

Figure 2: Micro-fluidic chip with varying channel width: 200, 400, 600, 800 and 1000 μm.

The channels were designed sufficiently wide to allow for U-turn trajectories (Figure 2). The magnetic field was applied by a miniature permanent magnet mounted on a computer controlled stepper motor. The field strength was varied by changing the distance between the microfluidic chip and the magnet.

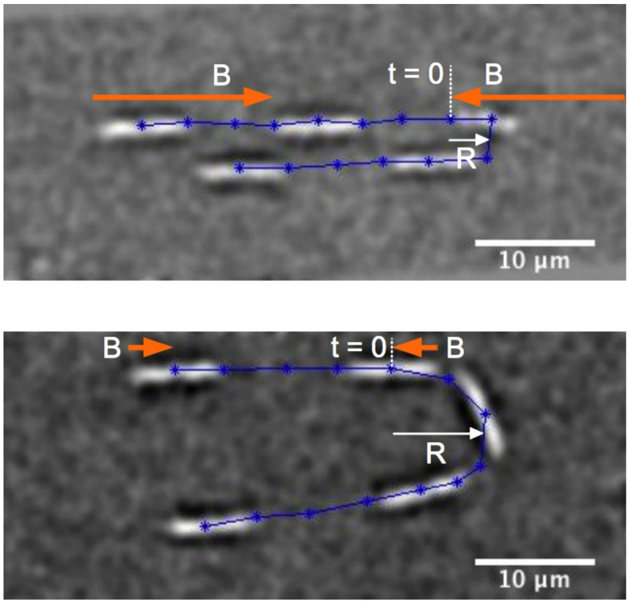

Figure 3: Top: U-turn trajectory with a radius of 2 μm at 0.2 mT. Bottom: U-turn trajectory with a radius of 8 μm at 0.05 mT. Velocity in both instances is around 25 μm/s for the entire sequence. Only a subset of images is shown.

RESULTS AND DISCUSSION

We observed a decrease in the U-turn radius of curvature length with increasing field strength from 0.05 up to 60 mT. Figure 3 shows a sequence of time-lapse images of the same bacterium for two different field strengths. Measurements at other field values for the same bacterium are summarized in figure 4, which shows the relation of v/R with the field strength up to 2 mT.

Above 2 mT the radius of curvature decreases below the resolution of the microscope. This results in limited observation of R smaller than 1 micrometer, below which value the u-turn trajectory cannot be accurately determined. The measurement scatter is caused by variation of bacterium velocity during the measurement. Within the resolution of our measurement however, the measurement is in agreement with the model.

From the slope of the curve we calculate the ratio of m over α to be 2.5.10^3 Ts^{-1}, which is in agreement with average values for magnetotactic bacteria (α = 40 zNs and m = 100 aAm^2). Furthermore, we observed that the turn-around time for MTB decreases with increasing field strength.

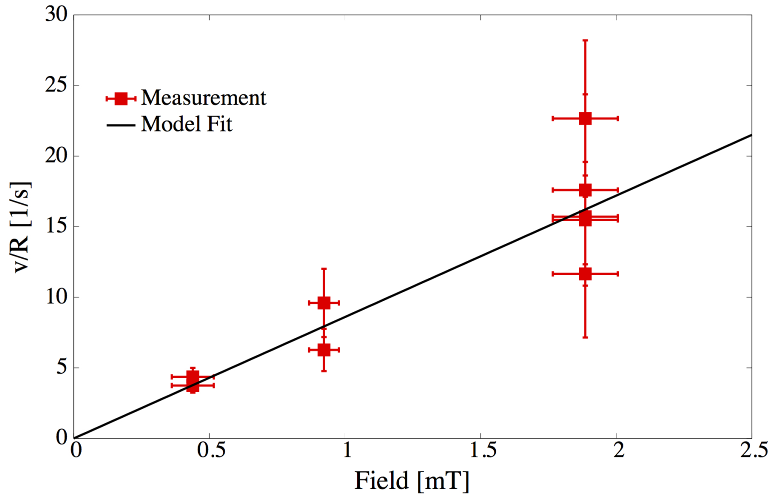

Figure 4. Relation of velocity over radius of curvature with applied field strength. The measurement data is consistent with the model (black line). The measurement scatter is caused by non-constant velocity of the bacterium.

CONCLUSION

These new observations of field dependence of MTB-trajectories are of primary importance to optimize the use of magnets and currents while controlling MTB inside complex microfluidic networks. It is one step further into the direction of using magnetically steerable self-propelled objects for the delivery of pay-loads such as drugs or micro-objects inside microfluidic systems, as proposed by [4].

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REFERENCES:

[1] “Dynamics of magnetotactic bacteria in a rotating magnetic field”, Kaspars Erglis, Biophysical journal, **93**:1402-1412 (2007)

[2] “Dynamic model and motion mechanism of magnetotactic bacteria with two lateral flagella bundles”, Cenyu Yang, Journal of Bionic Engineering, **9,** 200-210 (2012)

[3] “Experimental testbed for characterization and control of biological Microrobots”, Islam S.M. Khalil, Marc P. Pichel, Lars Zondervan, Leon Abelmann and Sarthak Misra, International Symposium on Experimental Robotics, Springer Tracts in Advanced Robotics, **88**, 617-631 (2012)

[4] “Microrobotics in the vascular network: present status and next challenges”, Sylvain Martel, Journal of Micro-Bio Robot, **8**, 41-52, (2013)

CONTACT

*Marc Pichel, tel: +49 681 9382 215; m.pichel@kist-europe.de