Magneto-mechanic model of the magnetotactic bacteria. Applications in the microactuator field

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The specific structural characteristic of magnetotactic bacteria (MTB) is the presence inside the cell of particles named magnetosomes which are magnetic nano-crystals [Balkwill et al. 1980]. Their specific functional characteristic is magnetotaxis, the orientation along the Earth`s geomagnetic field lines. Magnetosomes are defined as intracellular, magnetic single-domain crystals of a magnetic iron mineral that are enveloped by a membrane In many MTB strains the iron mineral particle consist of magnetite, Fe_3O_4, whereas in several MTB from marine, sulfidic environments, the iron mineral particle consist of greigite, Fe_3S_4.The size of magnetite crystals found in different strains is between 35-120nm.The paper includes the comentaries about the geometric model.There are also proposed two new applications and the authors present the structures of a news microactuators or manipulators) the control of the optically medium specific parameters with magnetic field and ii) the motion control of nanomagneto-manipulators driven by magnetic field.

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1. Introduction

In 1975 Robert Blakemore published his paper on magnetotactic bacteria (MTB).He stated that MTB's main functional characteristic is magnetotaxis, the orientation along the Earth` s geomagnetic field lines. Magnetotaxis is determined by the presence inside the cell of particles named magnetosomes. These were originally defined as intracellular, magnetic single-domain (SD) crystals of a magnetic iron mineral that are enveloped by a trilaminate strcuture, the magnetosome membrane (MM). In other words, magnetosome consist of magnetic iron mineral particles (the inorganic phase) enclosed within a membrane (the organic phase**)**. The organic phase (= the magnetosome membrane = the magnetosome vesicle), consists in *Magentospirillum* strains (*M.magnetotacticum* or *M.gryphiswaldense*) of a bilayer of about 3-4nm containing phospholipids and proteins [1].

Magentosome membrane is composed of protreins and lipids. Magnetosome proteins (MMPs) estimated to represent approximately 0.1% of the total cellular protein are either loosley attached or tightly bound to the magnetosome crystal. In *M. gryphiswaldense* there are at least 18 different *bona-fide* magnetosome membrane proteins (MMPs) grouped in several protein families that seem to be present in all MTB. Some of the families are not specific to MTB, being found also in other cells. A number of common lipids have been identified in isolated magnetoosmes of *M. gryphiswaldense* .

In *M. gryphiswaldense* the magnetosome inorganic phase consist of magnetite (Fe_3O_4); the size and morphology of magnetic crystals are species specific and uniform within a single cell, for example in *M. gryphiswaldense* the dimension of magnetosomes is around 45 nm. The magnetosomes are arranged in a single chain, magnetostatic interactions between the single-magnetic domain particles cause the particle magnetic moment to orient spontaneously parallel each other along the chain direction (Frenkel and Blakemore,1980), thus resulting a permanent magnetic dipole associated with the chain. Only such a chain structure allows the magnetosomes to behave together like a compass needle which orients the bacteria inside the relatively weak magnetic field of the Earth. In mutant cells, lacking one magnetosome protein, magnetosomes group together into irregularly ordered clusters.and not in a chain as in the wild type. In these clusters, because the magnetic moments of the individual magnetite crystals partially cancel each other out, the mutant cells can orient themselves only weakly in the magnetic field [2].

2. A magneto-mechanical model of the magnetic bacterium

The biological structure can be assimilated with a chain segmented with magnetic segments (the magnetosomes) that Fig. 1a.

Each magnetosome has the dimensions ; a_m, b_m, c_m (elipsoidal model) a volume v_i and having a magnetic dipole $\overline{m}_i$ with $i = 1...n.$ The each *Magnetospirillum gryphiswaldense* magneto-some is in a magnetic field $\overline{\mathbf{B}}_m$ and the angle between $\overline{m}_i . \overline{\mathbf{B}}_m$ being the angle θ_i [4](see Fig. 1b).

The magnetite cristal of magnetosome can be assimilated with an magnetic elipsoid [4,8] or like a magnetic dipole with magnetization charge ; $\pm\rho_m$ (at $\Delta\bar{r}$ distance) :

$$\bar{m}_i = -\mu_m \Delta\bar{M} = \rho_m \Delta\bar{r} \quad (1)$$

where

$$\rho_m = -\mu_m \cdot div\bar{M} \quad (2)$$

and

$$\Delta r = 2 \cdot a_c \quad (3)$$

with: μ_c -permeability of magnetosome domain, $\bar{M}$ - the magnetization which is constant inside of the elipsoid and has two components:

$$\bar{M} = \bar{M}_t(\bar{H}) + \bar{M}_p \quad (4)$$

$\bar{M}_t -$ temporary magnetization, $\bar{M}_p$ -permanent magnetization, $\bar{H}$ -magnetic field intensity.

The equation what describe the motion of magnetic bacterium submitted to the action of outer magnetic field [6]:

$$\frac{d\bar{L}}{dt} = \bar{F}_{fv} + \bar{F}_{mag} + \bar{F}_{visc} \quad (5)$$

where $\bar{F}_{fv}$ - friction force, $\bar{F}_{mag}$ - magnetic force, $\bar{F}_{visc}$ - viscous force.

A model f a magnetosome chain is presented in fig.2 where K_{mmi} and C_{mmi} are the spring scale and damping factor between two magnetosome, $K_{msxi}, K_{msyi}, K_{mszi}$ the spring scale and $C_{mszi}, C_{msxi}, C_{msyi}$ the damping factor between the magnetosome and membrane of the magnetic bacterium.

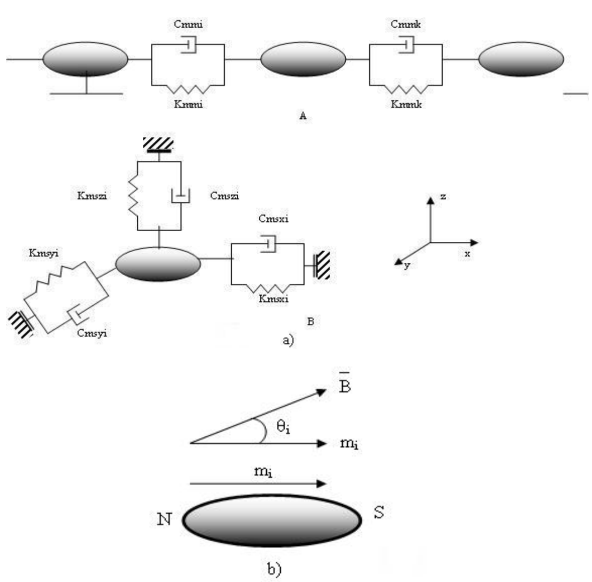

Fig. 1. The magnetosome chaine model of biological structure.

3. A new class of micro and nanomanipulators

The principal goal of remote manipulation is to extend human ability in remote locations as well as hazardous arms have been developed. MTB represents a remarkable nanostructure for a distinct manipulator class or division. The magnetosome and magnetosome chain microstructure belong to a category of manipulators termed continuum to refer robotics field .

For exemple the magnetosome chain microstructure can be move and control with a 3D system using magnetic levitation that represents an interesting microrobotic element.

Also, the magnetosome can be assimilated with the multijoint type Moray arm [7] (Fig. 2), which is characterized by a mechanism integrating a powerful prismatic joint (slider) at the arm as is defined by the curvature:

$$\Bbbk_{arm} = \begin{cases} k(s), 0 \le s \le l - x_s \\ 0, -x_s \le s \le 0 \end{cases} \quad (6)$$

The nanostructure of MTB suggests a nano or micromanipulator structure what includes a flexible chain support with flexible joins and with magnetic elements which are small permanent magnets.

These micromanipulator systems basically work within small magnetic gaps between the electromagnets (which generate the variable magnetic fields) and the motil chain.

In Fig. 3 are presented some structures of flexible and rigid manipulators.

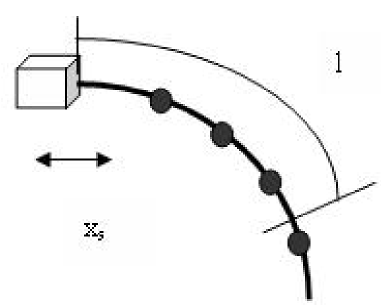

Fig. 2. A Moray multijoint.

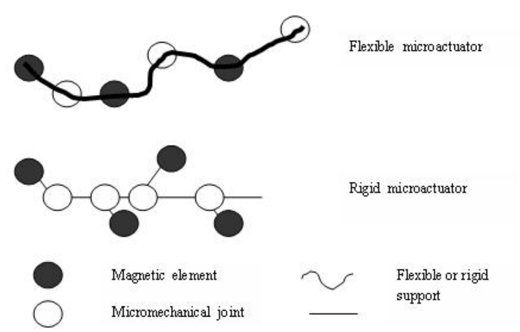

Fig. 3. Microarchitecture of nano or micro-magneto-manipulators.

The drive units for this microactuators consists of microelectromagnets and the microactuators are manipuled in a workspace by regulating magnetic field.

4. A structure of a manipulator

The main structure of a mechano-magnetic manipulator based on magnetotactic bacterium Magnetospirillum gryphiswaldense is presented in Fig. 4.

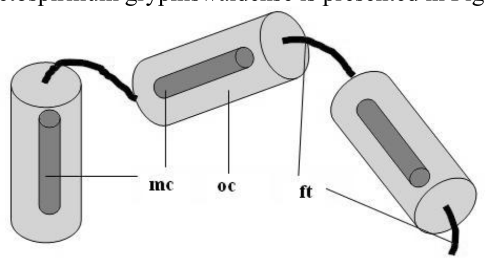

Fig. 4. Main structure of an magnetomechanic manipulators: mc - magnetic core, oc- outer cover, ft- flexible thread (wire).

If nanomanipulation is defined as positionng and/or orientation control of nanometer scale objects with nanometer resolution [3], then class of manipulators presented and based on the biostructure of *Magnetospirillum gryphiswaldense* magnetic bacterium can be assimilable with the nanomanipulator class.

In Table 1 are presented the dimensions and the material of the guide mark of this manipulator what is in building to INCDIE CA.

Table 1. Dimensions and material of manipulator.

Guide mark	Diameter[mm]	Length [mm]	Material
Magnetic core-mc	1,5	1,5	
Outer cover-oc	1,9	2	
Flexible thread -ft	0,2	3	PVC

5. Applications

Some applications can be the micro or nanooptical scanners (Fig. 5) where the optical beam is scanned and controlled by the motility of magnetic bacterium in outer magnetic field.

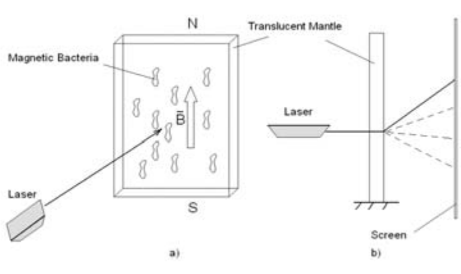

Fig. 5. An optical scanner with micromagnetic manipulator applications.

6. Conclusions

The paper presents the main elements of magnetotactic bacterium of mechano magnetic modelling and a new structure of a micromanipulators which was built by the authors without realise the experimental investigations. The authors intend to develop some applications with this micromanipulator tips.

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