Modeling and Optimization of Planar Micro-Coils Integrated in Microfluidic Devices

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Abstract— *Magnetic actuation in miniaturized systems has emerged as strategic tool to perform microfluidic functions based on the manipulation of functionalized micro beads.An integrated planar coil is the most appropriate compenent used to manipulate paramagnetic micro bead in BioMEMS. Located under microfluidic channels, they can generate a sufficient magnetic field, according to their topologies and sizes, to trap or release surface functionalized beads. We have simulated the magnetic field induced by different micro-coils configurations by using the Finite Element Method (FEM) numerical analysis. The objective is to evaluate and optimize the magnetic field produced by each configuration and hence the magnetic forces exerted on microbeads circulating around micro-coils. Finally, the effect of different coil parameters such as the surface section of conductors, number of turns and inter-coil distance is discussed. The main advantage of the established model is to take into account all the technological parameters of the microfluidic device and to give the possibility to optimize geometrical parameters in order to integrate planar micro coils and to evaluate their action on the move of paramagnetic beads circuling in microfluidic channels.*

Index Terms— Planar Microcoil, Finite Element Method (FEM) modeling, Magnetic field, paramagnetic beads, microfluidics

I. INTRODUCTION

Magnetic actuation in miniaturized systems has become an important tool to insure microfluidic functions based on the manipulation of functionalized micro beads [1]. The principal advantage to use magnetic forces to trap or move miniaturized objects is the absence of contact with the fluid. Planar micro coils have the potential to be integrated in microfluidic systems and to be used as actuators controlled by external electronic circuits.

In this paper we study different designs of planar micro-coils by using Comsol Multiphysics software in order to evaluate device behavior and to optimize its design. The established models will be used to evaluate and to maximize the strength, the flux and the resultant force of the magnetic field generated by micro-coils on micro beads circulating in microfluidic devices. A parametric analysis is carried out to discuss the influence of different geometrical and electrical coil parameters on the induced magnetic field and to select the most effective device among designs studied.

The selection criterion is to get the device that will generate the most effective magnetic force possible for trapping and the manipulation of magnetic microbead. Hence, by using a Finite Element Method (FEM) to simulate structures with microbeads, we demonstrate that the trapping performances are strongly linked to dimensions and shapes of both micro-fluidic channels and micro-coils as well as their location in the microsystem.

II. INFLUENCE OF MICRO-COILS PARAMETERS

As reported in Table I, four micro-coil designs have been studied. The simulation was performed to evaluate and optimize, for each configuration, the magnetic fields generated by actuators and hence the magnetic forces produced to trap the maximum number of paramagnetic beads circulating near them.

Figure 1 shows schematic representation of a square spiral microcoil with the following geometrical characteristics: number of turns (N = 4), width of spire (r = 5µm), thickness of spire (e = 5µm) and inter-coil distance (a = 5µm)

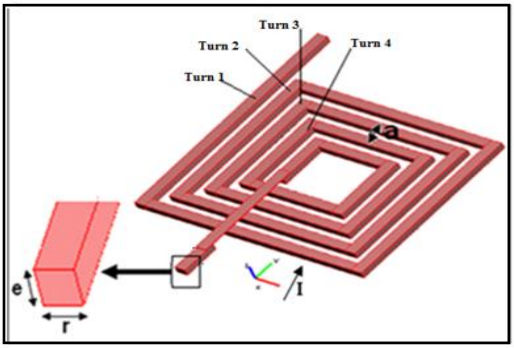


Fig. 1 Tridimensionnal representation of a square spiral micro-coil (N=4, e=5 µm, r=5µm and a= 5µm).

For a fixed square geometry of micro-coils, the principal parameters influencing the efficiency of bead trapping are : surface section of conductors, number of turns and inter-coil distance. The for designs studied in this work are reported in Table I.

TableI. List of designs and parameters studied for a square spiral micro-coil.

 **3D representation**	**Number of turns**	**Wire section (µm*µm)**	**Inter-coil distance (µm)**
Design 1	5	5*5	5
Design 2	5	5*10	5
Design 3	10	5*5	5
Design 4	5	5*5	10

A. Influence of surface section of conductor (S)

Fig.2 shows the amplitude of the x- and z- components of the magnetic field generated by respectively two square micro-coils: the one having 5 turns and the conductive copper lines of 5µm width and separated by 5µm; the other having lines of 10 µm width and separated by 5 µm. The magnetic evolution of BX and BZ are recorded at a height distance of 5µm into the microfluidic channel and for an excitation current I=100 mA. It is observed that their values increase when the conductors of 5µm wide are separated by 5µm compared to those of 10µm width separated.

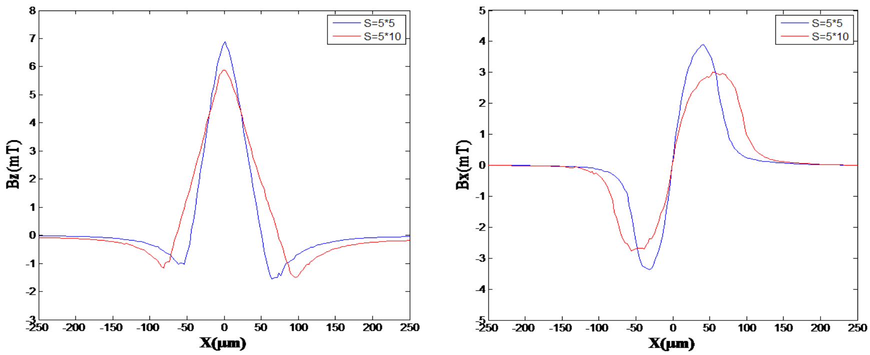
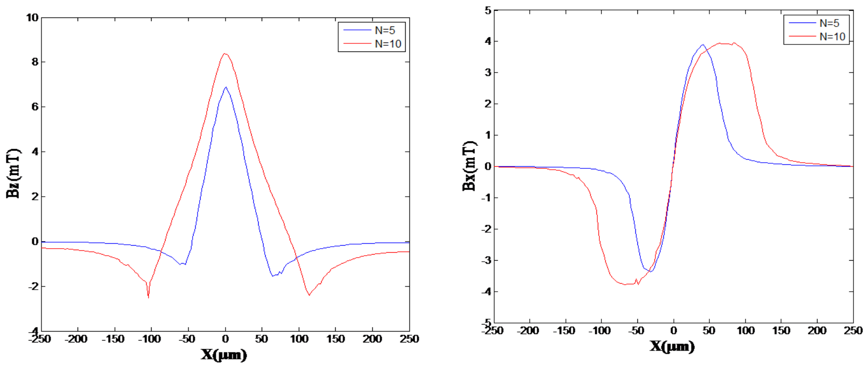


Fig.2 Magnetic field (Bx and Bz) generated by a spiral micro-coil with 5 turns as function of a the conductor section (S = 5µm*5µm and S = 5µm *10µm) at a height of 5µm into the micro-channel and I = 100 mA.

B. Influence of wire turns (N)

The magnetic field behavior (B_X and B_Z) generated by the two micro-coils (N = 5, S = 5 µm *5 µm) and (N = 10, S = 5 µm * 5µm) are illustrated in fig. 3. Thus, doubling the number of turns (5 and 10 turns) enables to increase the components of the magnetic field B_X and B_Z field, always in accordance with the principle of superposition of the magnetic field generated by each segment of the coil. However, this increase remains low.

Fig. 3 Magnetic field components (B_X and B_Z) determined at a height of 5µm into microchannel based on the number of turns (10 and 5) for I = 100 mA



andsection conductor (S = 5µm *5µm)

Fig. 3 Magnetic field components (BX and BZ) determined at a height of 5µm into microchannel based on the number of turns (10 and 5) for I = 100 mA and section conductor (S = 5µm *5µm).

C. Influence of inter-wires distance (a)

We also vary the spacing inter-turn of microcoil with 5 turns, square conductor section (5µm x 5 microns) and an intensity I = 100 mA. The evolution of components of the magnetic field BX and BZ for 5µm into channel or 10µm above the micro-coil are shown in fig.4. In view of these results, it is clear that the decrease the inter-spacing turns between each conductor line (5µm to 10 µm) leads to an increase of 1.32 times near the component of the magnetic field BX and about 1.17 times the component of magnetic field B_Z.

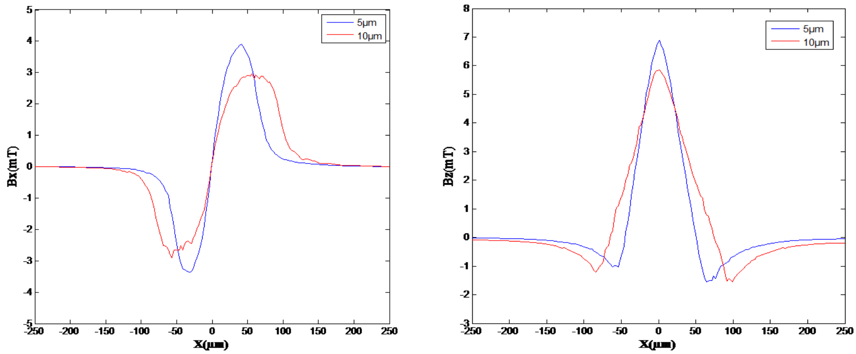


Fig. 4 Components of magnetic field (BX and BZ) generated by the square micro-coil with 5 turns at a height of 5µm into microfluidic channel, for the inter-turn distance (5µm and 10µm) and I = 100mA.

III. COMPARAISON SIMULATION-EXPERIMENTS

In order to validate our Finite Element Method (FEM) approach modeling with Comsol Multiphysics software we compare our results with those obtained by R. Fulcrand and al. [2]. We reported in Table II the values of the components of the magnetic field and the magnetic force calculated at a height of 5µm into micro-channel and supplied with a current of I=100 mA. These results confirm the good correlation between the two results. Thus, we confirm that our model developed is a powerful for parametric optimization.

Table II. Maximum magnetic field level (BXmax and BZmax) and magnetic force (FXmax and FZmax) obtained for I = 100 mA,at height of 5µm into micro-fluidic channel for the square micro-coil with 5 turns , section conductor S = 5µm x 5µm, and inter-coil separated by 5µm

Bxmax	4.04 mT	4.59 mT
Bzmax	6.76 mT	6.48 mT
Fxmax	1.21 pN	1.26 pN
Fzmax	2.91 pN	2.76 pN

IV. CONCLUSION

In this study, we have reported the main results of the modelling of different designs of a square micro-coil for use as an actuators to control the displacement of paramagnetic beads circulating in microfluidics channels. We demonstrated that the dimensions of the conductor and their positioning in the coil, together with the rapprochement of turns are an important parameter to superpose the fields induced by each segment of the coil and to increase consecutively the magnetic field intensity. These same wires must also have a square section in which a strong current density can circulate into the mico-coil. The number of turns is also an important parameter: it has little influence on the value of the component in the x-direction (BX). We show, however, that the component along z axes BZ crosses of 6.9 mT to 8.4 mT when the number of turns is doubled (5 to 10 turns).

These results show that the square configuration of planar microcoils allow to obtain magnetic fields, for a current intensity I = 100mA, having a maximal amplitude of around 2 at 6 mT, generating hence forces near 1 to 3 pN. These values are comparable to those published in literature [4-6].After these comparisons of the studied designs, it appears that the best device is a square spiral microcoil with a large number of the finest and tightest turns possible.

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