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Magnetic Wireless Actuator for Medical Applications

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The largest advantage of magnetic micromachine is wireless operation. This advantage makes it suitable for medical micromachine working inside the human body. In the medical field, low invasion treatment is very important. From this point of view, very small machines working in the body without power supply cables meet the needs of the medical field. In this paper, we report about magnetic wireless actuators for medical applications.

Key words : magnetic, micromachine, medical, low invasion

1. Introduction

Magnetic systems possess superior characteristics as driving micromachines. Energy for working the machine can be applied by an external magnetic field. Therefore the machine can work without power supply cables in the field. It is suitable for the micromachine to supply the energy using a magnetic field, because it is easy to supply the magnetic field to the limited area, which the micromachine works. By this system, wireless micromachines can be obtained.

There are two basic principles for driving the magnetic micromachines. One is the force acting on the magnetic pole in the gradient magnetic field. The other is the torque acting on the magnetic moment in the uniform magnetic field. Using these principles, magnetic micromachines have been investigated [1-3].

The advantages of the magnetic micromachines suggest their application to the medical field. In the medical field, low invasion treatment is very important. From this point of view, very small machines working in the body without power supply cables meet the needs of the medical field. In this paper, we report two kinds of the magnetic micromachines. One is spiral-type magnetic micromachine, which would be able to run in the body. The other is the active bending system for the catheter, which enables the selection of the pathway at the branches in the blood tubes or the bronchial tubes.

2. Spiral-type magnetic micromachine

2.1. Basic Principle

Spiral-type magnetic micromachines are composed of magnets, cylindrical body and spiral shape. Figure 1 shows the basic structure of the spiral-type magnetic micromachine. Because the magnetization of the magnet is aligned to the diameter, the machine rotates in a rotational magnetic field. When the machine rotates in a fluid or a gel, the spiral shape produces the thrust force.

This machine has remarkable features. We could control the swimming direction of the machine. The machine swam to the direction perpendicular to the rotating field plane. This plane was an imaginary plane that the field vector rotates in it. By controlling the direction of the plane, we could steer the machine to any direction [4]. The machine of 1.2 mm diameter and 15 mm length could swim against the water flow over 70 mm/s [5]. This velocity was larger than the flow speed of the blood in the main vein. To optimize the shape of the machine, the

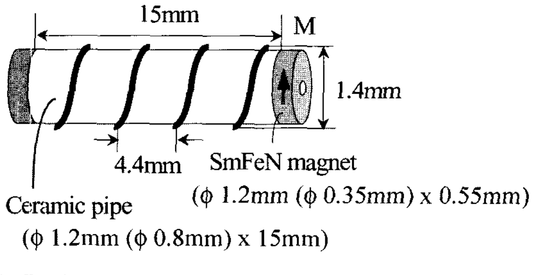

Fig. 1. Basic structure of the spiral-type magnetic micromachine.

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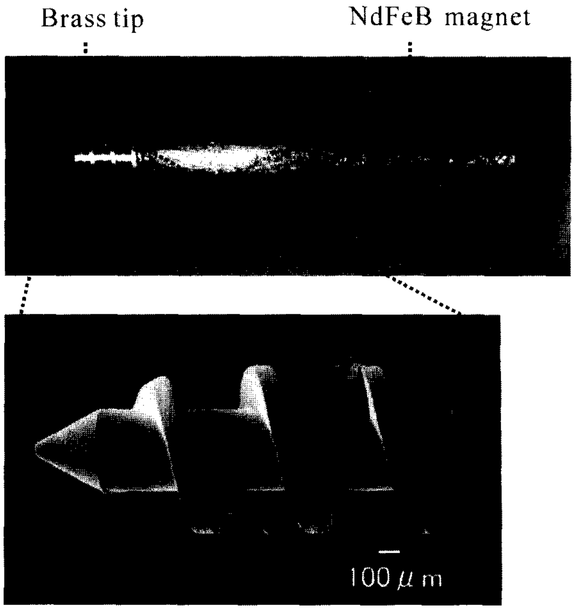

Fig. 2. The spiral-type magnetic micromachine for gels.

swimming properties of the machines were analyzed using the finite volume method [6]. According to the analyzed results and experimental results, the machine could swim under wide Reynolds number condition (10^{-7} ~10^{3}). This result clarified the machine is suitable for miniaturization [7]. The machine can work not only in a liquid but also in a gel. Experiments using agar and bovine tissue have been reported [8-9].

According to these previous results, the new function for this machine was studied. This paper reports two functions of the machine. One was independent control; the other was obtaining a heating machine.

2.2. Individual control of the machines

For medical applications, it is required that several machines work individually in the same magnetic field. To obtain individual movement, the shapes of the machines were varied. Figure 2 shows the machine for operation in a gel. It is composed by a screw tip and by a rod-shape NdFeB magnet. The residual magnetization of the magnet was 0.98 T, and it was magnetized to the direction of the diameter. The diameter of the machine was 0.8 mm. A medical injector can insert this size of machine. By applying the rotational magnetic field the machine rotated and moved in the agar. Five kinds of machines were fabricated as shown in Table 1. By changing the shape of the screw, the velocity varied drastically. The results are shown in Fig. 3. For example, the machine A has a velocity of 16 mm/s in the rotational field of 40 Hz, while the machine C moved in less than 1 mm/s.

Table 1. Variation of the spiral shape of the machines

	Spiral pitch (mm)	Spiral height (mm)
A	0.5	0.2
B	0.5	0.3
C	0.5	0.1
D	0.3	0.2
E	0.8	0.2

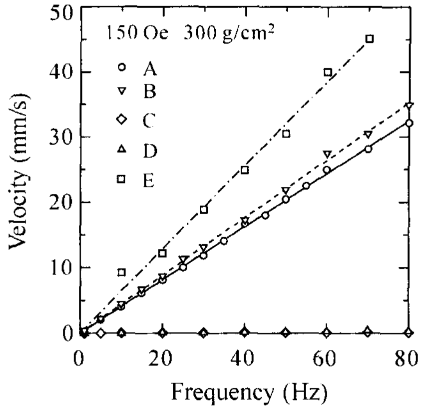

Fig. 3. Frequency dependence of velocity of the spiral-type magnetic micromachine in the gel.

Using this property we tried to operate the several machines individually. Fig. 4 shows the result of the experiment. The machine A and C (described in Table 1) were used for the experiment. On this experiment, the length of the magnet of the machine A and C was 6 mm and 9 mm, respectively, because of controlling the step-out frequency. When the frequency of the external fields equals to step-out frequency, the machine cannot synchronize to the field, because a load torque of the machine is equals to the magnetic torque. By applying a field of 1 Hz, both machines were synchronized to the field. The machine A moved faster because of the difference of the moving property. When the frequency of the field was changed to 80 Hz, the machine C was still synchronized, but the machine A could not be synchronized because the magnetic torque was smaller than the load torque for the rotation frequency of 80 Hz. Therefore the machine C only moved in this frequency and overtook the machine A. The field frequency was reduced to 1 Hz again, the velocity of the machine C became smaller, and the machine A moved faster because the machine could synchronized again to the field.

This experiment suggested that we could control several machines in a uniform magnetic field by changing the frequency or the intensity of the field.

2.3. Heating machine

For the medical application of this machine, the impor-

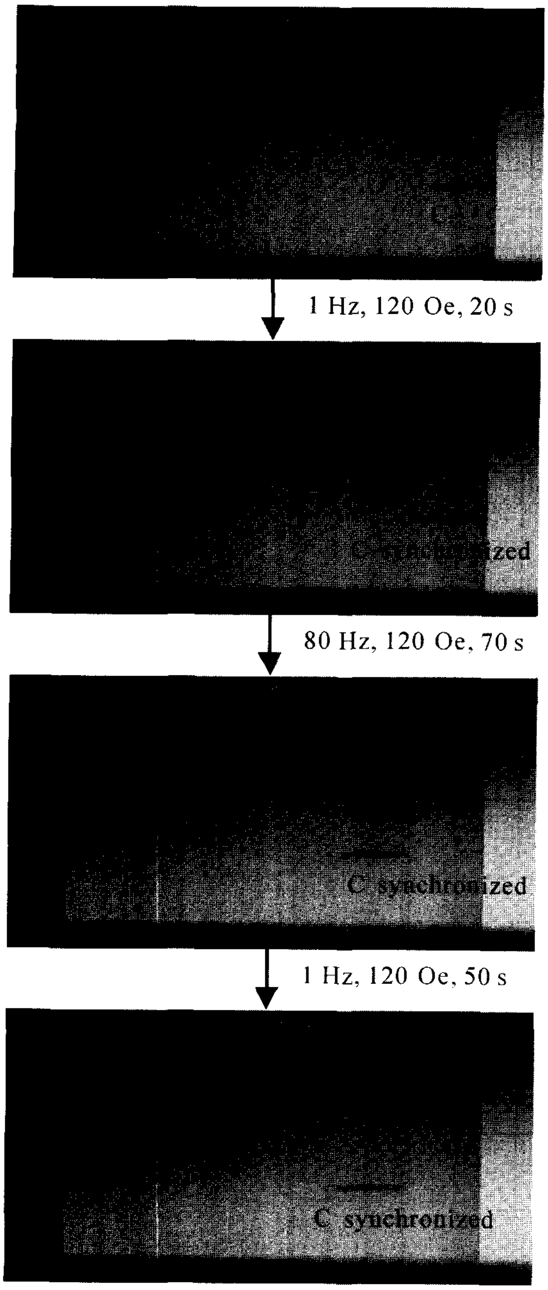

Fig. 4. Individual operation of the spiral-type magnetic micromachines in gel.

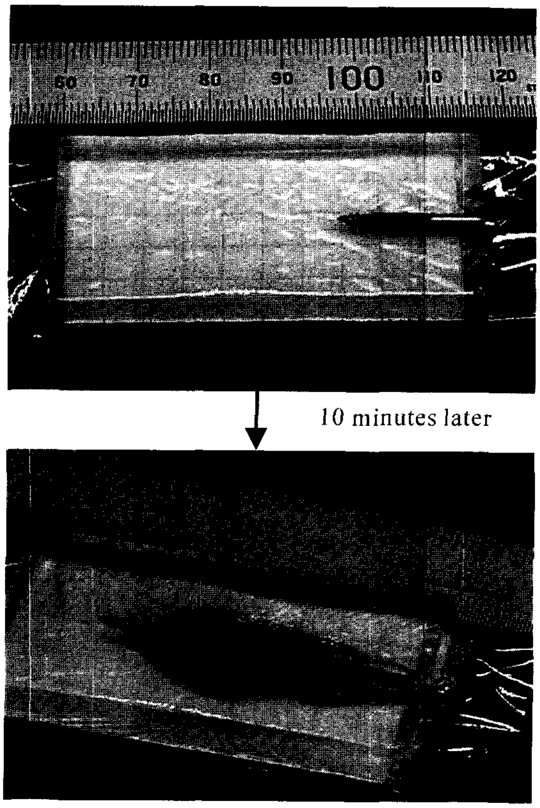

Fig. 5. The experimental result of the heating test of the spiral-type magnetic micromachine.

tant point is its function after arriving at its destination. We proposed a heating mechanism attached to this machine. It is well known that magnetic materials placed in an alternating magnetic field produce heat by the magnetic loss. We produced a heating machine by attaching a permalloy rod to the machine. By applying the rotational magnetic field for moving and the alternating field for heating in same time, the machine heated and moved in agar.

We set the heating machine in the agar. A thermosensitive sheet was set beneath the machine. The color of the sheet changes from white to red at 50°C. The field of 12 kA/m with rotation frequency of 1 Hz and the alternating field of 100 kHz and 6.4 kA/m were applied in same time. Figure 5 shows the result. In 10 minutes, the machine moved 25 mm and heated over 50°C. Boiling the agar on the machine formed a bubble at the right end of the agar.

This means the wireless heating machine could be obtained using the alternating magnetic field and rotational magnetic field. This machine had the great possibility for local medical operation for cancer.

3. Active bending for the catheter

3.1. Principle of the bending and experimental results

For medical equipment such as a catheter or an endoscope, it is required to bend its end to select the way at blanches inside of the body to reduce the pain of the patient during the operation. There were some previous works to obtain the active bending of the catheter using a shape memory alloy [10] or an electro-elastic materials [11]. However these methods were very complicated and had poor response.

Fig. 6. The guide-wire with the magnet on the tip.

We firstly proposed a method to bend using magnetic torque. It is well known that the magnet in the uniform magnetic field produces magnetic torque. This principle was used for driving the magnetic micromachines. For bending by this principle, we needed a tiny magnet only on the tip of the catheter. By applying a dc magnetic field from outside of the body, the bend was produced by the magnetic torque.

In the experiment we used a medical guide-wire, which was used to insert the endoscope or some other medical equipment. The diameter of the guide-wire was 0.9 mm at the bottom, and 0.5 mm at the tip. To avoid hurting the body, the tip of the guide-wire is soft and flexible. The magnetic guide wire was obtained by attaching a NdFeB magnet of 0.7 mm-diameter and 4.7 mm-length at the tip of the guide-wire. The residual magnetization and the coercive force of the magnet were 0.952 T and 1.15 MA/m, respectively. Figure 6 shows the photograph of the magnetic guide-wire used in the experiment. The dc magnetic field was applied to the guide-wire using two pairs of Helmholtz coils set in perpendicularly. These coils could produce 48 kA/m of magnetic field in maximum in the area of 200 mm-diameter sphere. The currents of the coils were controlled by a controller connected to a computer. Using this system, we could control the magnitude and the direction of the magnetic field vector.

The guide-wire could be inserted to the certain destination position inside the body. After that, a flexible tube called guide-sheath was inserted over the guide-wire. When the end of the guide-sheath arrived at the destination, the guide-wire was pulled out through the guide-sheath. After this operation, the medical equipment could insert through the guide-sheath. Therefore inserting the guide-wire was very important for applying the insert-type medical equipment.

Using this system, we tried to insert the magnetic guide-wire into a bronchus model. The size of the model was same as the bronchus of human. With applying the controlled magnetic field, the guide-wire could be inserted to a certain position in the bronchus model as shown in Fig. 7. This result shows that this system is useful for inserting the guide-wire to the position difficult to access.

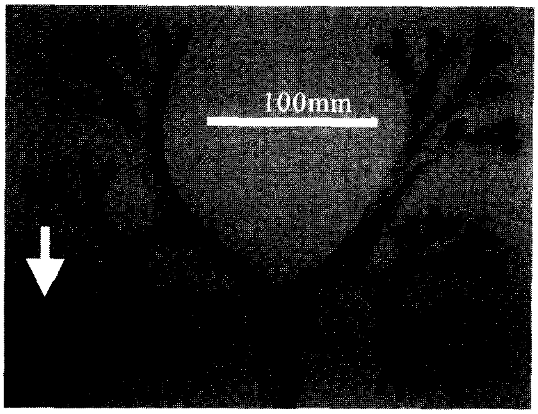

Fig. 7. The guide-wire inserted into the bronchus model. The end of the guide-wire reaches to the position of arrow.

3.2. Discussion

The greatest advantage of the magnetic guide-wire proposed is its wireless operation. Therefore the bending system requires no additional cables on the guide-wire. This makes the magnetic guide-wire simple and easy to produce.

The produced torque was varied by applied field strength and the size of the magnet. The magnet used in the experiment had the residual magnetization of 0.952 T. Therefore the maximum produced torque in the field of 23.9 kA/m was 41 μNm. If the size of the magnet reduced to the diameter of the guide-wire as 0.5 mm, the torque is reduced to 71%. However the same torque would be produced on the small magnet by applying a larger field of 33.7 kA/m. This means that the system is suitable for thinner guide-wire.

The bending response is also important factor for the medical application. There is no delay of magnetic torque on the applying magnetic field. Therefore the obtained guide-wire can bend according to the intention of the doctors without time delay. The quick response is great advantage of the magnetic guide-wire compare with the method using the heat.

4. Summary

The magnetic micromachines have been rarely used for medical application. However, to obtain the low invasion medical treatments, the magnetic methods are very important, because the method can apply the energy to move for the machine without wire.

This paper reported two magnetic micromachines for medical applications. The micromachines were found to have suitable properties for medical applications. We hope this system would be widely used in medical fields. We will confirm the function of the machines by experiments using a human model and animal test.

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