Inducing magnetic torque inside an MRI scanner using pulsed magnetic gradients

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Introduction: Magnetic Resonance Imaging scanners have proven to be an extremely powerful tool for the navigation of magnetic particles inside the human body[1,2]. Among the potential future applications of magnetic resonance navigation (MRN) is capsule navigation for gastrointestinal (GI) examination. With the development of miniaturized cameras and electronics, it is now possible to embed camera, flashing light emitting diodes (LED), wireless transmission circuits and battery in tiny capsules, swallowed by the patient[3,4]. Nevertheless, without a locomotion mechanism, the capsule may miss abnormal tissue since it relies only on random motion of the device within the body and periodic image acquisition. Magnetic actuation is one of possible control solutions. Commercial prototypes of magnetic actuated capsules have already been demonstrated by Siemens and Olympus[5], and Stereotaxis[6] but their use requires a dedicated scanner. MRN is currently limited to translations only due to the impossibility to rotate the strong external B_0 field. This constraint is a barrier to the development of MRI actuated capsules since imaging of small abnormalities may require fine camera position and angle adjustment. The paper aims to demonstrate a means to induce a magnetic torque on a small capsule using the magnetic gradients of an imaging coil.

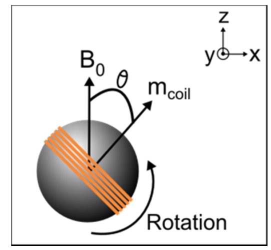

Figure 1 – Initial position of the capsule

Methods and Materials: To simplify the calculation, we derive here only the 1D case. A z-gradient coil generates a change of magnetic field amplitude along z equal to $\Delta B_z = G_z \times (z - z_0) = G_z \Delta z$, where G_z is the amplitude of the magnetic gradient, and z_0 is the center of the gradient field**.** Therefore, an alternating magnetic field can produce a change of magnetic flux Φ in a small coil (N turns) which in turn induces an electromotive force

$$\epsilon = -N\frac{d\phi}{dt} = -N\frac{d}{dt}\left[\oint\!\!\oint_{S_{coil}} G_z \Delta z\,(\boldsymbol{z}.\boldsymbol{dS})\right] = R_{wire} I.$$

As a result, a current flow establishes and a magnetic torque equal to

$$\boldsymbol{\tau} = \boldsymbol{m_{coil}} \times \boldsymbol{B_0} = NI\boldsymbol{S_{coil}} \times \boldsymbol{B_0} = \frac{\epsilon}{R_{wire}} NSB_0 sin\theta \boldsymbol{y}$$

is exerted on the coil. θ is the angle between the magnetic moment of the coil $\mathbf{m_{coil}}$ and the $\mathbf{B_0}$ field (see Figure 1).

The gradient pulses are generated by a shielded BFG-240/150-S-7 micro-imaging gradient coil (Resonance Research Inc., USA) placed at the center of a 1.5T Siemens Sonata MRI Scanner. The capsule is an assembly of a 2.5-cm diameter foam ball and a 5-turn coil made of copper wire. Visual feedback is provided by a MR-compatible camera, placed above the setup (see Figure 2b). The capsule is allowed to rotate only around the y axis.

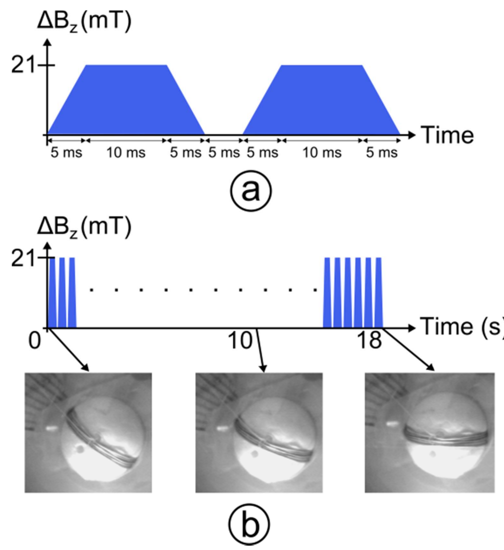

Figure 2 – (a) Shape of the gradient pulses (b) Video frames showing the rotation of the capsule after 0, 10 and 18 seconds.

Results: With the application of consecutive square gradient pulses (see Figure 2a), the capsule starts to rotate around the *y* axis from an angle of 34° (see Figure 2b). Angular position, measured from the video frames, and angular velocity are plotted in the Figure 3. 9 cm away from the center of the coil, the magnetic field swing is maximal and equal to 21 mT. With a rise time of 5 ms, it is equivalent to 4.1 T/s, well below stimulation threshold levels, and below clinical MRI performance.

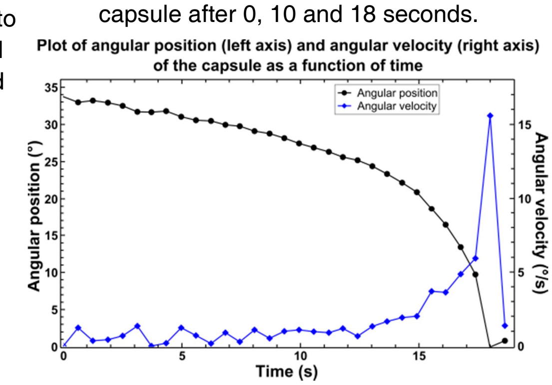

Figure 3 – Capsule angle and velocity as a function of time

Discussion and Conclusions: We have demonstrated that it is possible to induce a magnetic torque using pulsed magnetic gradients inside an MRI scanner. The magnetic field swing required is below stimulation levels and can be generated by a clinical MRI scanner. An improved design is currently underway. The possibility to generate rotation inside an MRI scanner may lead to the emergence of MRI actuated endoscopic capsules that could be remotely navigated, rotated, and tracked to precisely identify abnormal tissues in the GI tract.

References

1. Martel S, Mathieu J-B, Felfoul O, et al.*Appl Phys Lett*. 2007;90(11):114103-114105. doi:10.1063/1.2713229.
2. Pouponneau P, Leroux J-C, Soulez G, Gaboury L, Martel S.*Biomaterials*. 2011;32(13):3481-6. doi:10.1016/j.biomaterials.2010.12.059.
3. Pan G, Wang L. *Gastroenterol Res Pract*. 2012;2012:841691. doi:10.1155/2012/841691.
4. Basar MR, Malek F, Juni KM, Idris MS, Saleh MIM. *Int J Antennas Propag*. 2012;2012:1-14. doi:10.1155/2012/807165.
5. Keller H, Juloski A, Kawano H, et al. *2012 4th IEEE RAS EMBS Int Conf Biomed Robot Biomechatronics*. 2012:859-865. doi:10.1109/BioRob.2012.6290795.
6. Carpi F, Kastelein N, Talcott M, Pappone C.*Biomed Eng IEEE Trans*. 2011;58(2):231-234