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# MRI-COMPATIBLE TRANSCRANIAL MAGNETIC STIMULATION COIL ARRAY

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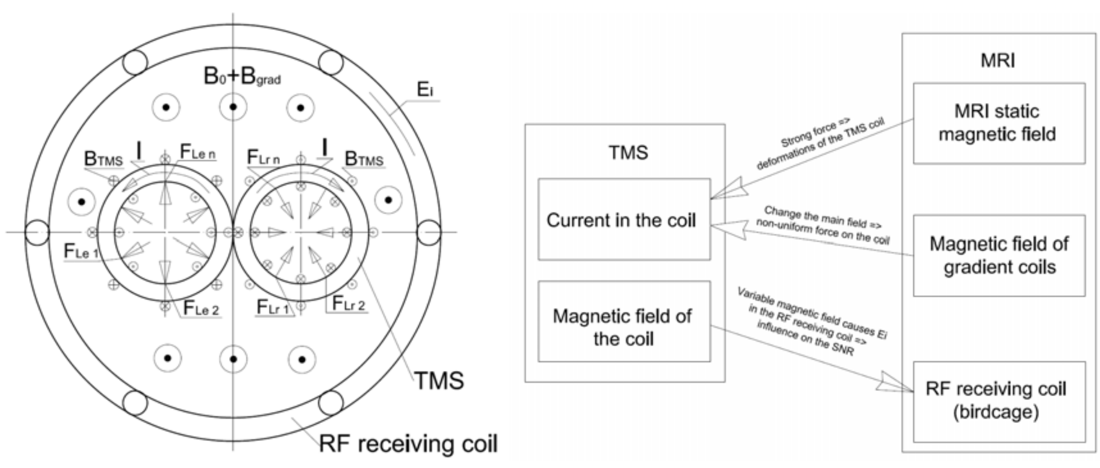
**Abstract**. This paper concerns the investigation of the interaction between MRI and TMS coils. Ensuring the compatibility of TMS systems with the MRI faces many of different engineering problems, for example, B field coupling, electromagnetic coupling, the strong Lorentz force, mechanical deformations and other tasks. Interaction between MRI magnetic fields and TMS coils generates forces and torques that significantly complicate the application of TMS and MRI systems. The static magnetic field produces the large Lorentz force acting on TMS coils. The gradient fields superimpose on the static field and make the summary field non-uniform. Non-uniform magnetic field produces non-symmetrical load on coils.

**Keywords**: Coils, interaction, magnetic resonance imaging, transcranial magnetic stimulation.

## INTRODUCTION

MRI systems are actively used for diagnostic purposes due to their ability to generate three-dimensional images of considerably high resolution. MRI – magnetic resonance imaging is a big system that produces the large field for implementation of the diagnostic process. The TMS technology provides a way to treat many neurological disorders that can be diagnosed with the aid of MRI [1][2]. Ensuring the compatibility of TMS systems with the MRI opens the possibility to treat and observe the effect of the treatment in real time. This task has the large number of different engineering challenges. The first challenge is the interaction between the MRI static magnetic field ($B_0$ = 1÷7 T) and the current in the TMS coil (fig. 1a). The strong Lorentz force $F_L$ that arises due to such interaction causes mechanical deformations. The second challenge is related to gradient coils $B_{grad}$ which change field $B_0$. This change leads to non-uniform load of the TMS coil $F_{Le\,1} \dots F_{Le\,n}$, $F_{Lr\,1} \dots F_{Lr\,n}$ (fig 1a). Also it is important to take into account that TMS coil is located near the RF receiving coil. The variable magnetic field produced during pulses in the TMS coil induces electromotive force ($E_i$) in the RF receiving coil and reduces the value of signal-to-noise ratio. There is no necessity to consider coupling between the TMS coil and the RF transmit system, because they are working at different times and do not correlate to each other. Figure 1 illustrates the magneto-electro-mechanical coupling of TMS coil array inside MRI.

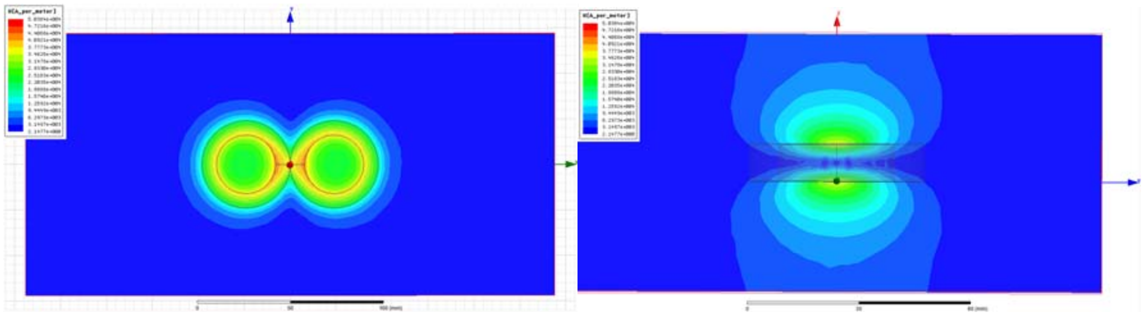



(a) (b)

**Figure 1.** a) Magneto-electro-mechanical coupling of TMS coil array inside MRI; b) three main problems of the concurrent MRI/TMS system.

TMS coils should successfully impact on specific parts of the human brain and cause positive effects aimed to treat neurological disorders. Impermanent nature of activities in the cerebral cortex makes additional difficulties. Brain activities change their location due to treatment and, therefore, it needs to be taken into account by changing the location of magnetic field exposures. This problem can be solved by using array of small coils. An array of coils allow single point impact on selected regions of the brain and because of the small size the influence the gradient field is small. Also coils will be placed at different angle with respect to the $B_0$ field and loads acting on coils will be different.

Thereby the presentation of the calculation of forces and torques that impact on TMS system inside MRI is the main purpose of this article. FEM is used to calculate forces, torques and mechanical deformations of coils. The starting point is the simulation of loads acting on 8-figure TMS coils which are widely used nowadays [3]. These coils have an opposite current direction in their windings. The opposite current direction enables to obtain a maximum magnitude of the magnetic field in the center (figure 2). ANSYS 3D Maxwell is used to simulate the magnetic field produced by the copper coil with inner radius 16 mm, outer radius 24 mm, height 10 mm and current 1 kA.



(a) (b)

**Figure 2**. Magnetic field intensity produced by 8-figure coil with opposite current direction: a) xy –plane; b) yz – plane.

Further it is necessary to set the main field $B_0$ and the gradient field, which have the greatest influence on the TMS coil. Forces and torques that act on the coil or coil arrays will be presented. The size and shape of coils will necessarily vary. Relationship between the load produced by the gradient field and the diameter of the coil will be shown. Small coils are less susceptible to the influence of the gradient field. Load acting on them is almost uniform and the influence of the gradient field can be neglected. In one set of the simulations, the angle of the coil relative to the main field should be constant and only the dimensions and shape will be varied. In another set, the shape should be constant and the angle between the coil and the field $B_0$ will change. Relationship between forces acting on the TMS coil and the angle should be shown. In this way, forces and torque as functions of the shape, size coils and the location will be demonstrated and analyzed in the full paper.

The large Lorentz force produced by the superconductor magnet cannot be eliminated by the design of the coils and their proper placement. This force exists all time and there is no possibility to remove it.

(1) $$\vec{F} = \iiint_V \vec{I} \times \vec{B}\, dV$$ , where

$\vec{F}$ - force on a current-carrying wire; $\vec{I}$ - current; $dV$ - infinitesimal volume; $\vec{B}$ - magnetic field (1.5, 3 T).

## CONCLUSIONS

Behavior of the TMS system inside MRI will be shown by representing results of calculation forces and torques that appear due to interaction between magnetic fields produced by MRI and the current in TMS coils. Consideration of the forces and torques applied to the coils can afford to build a system capable exist inside MRI.

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