Analysis of Non-linear Magnetic Core for Magnetic Neural Stimulators

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Magnetic stimulation is a non-invasive technique to stimulate the central and peripheral nervous system. Using time-varying magnetic fields, a magnetic stimulator induces eddy currents in the tissue to achieve neural excitation (M. Yamaguchi et. al., *JAP*'89). Due to a non-invasive technique, it has been used in a variety of clinical applications which include brain mapping, treatment of mood disorder, treatment of epilepsy, and treatment of chronic pain. Traditionally, magnetic stimulators consume high power and cause significant heat dissipation in the coil. Thus, use to these devices has been limited to transcranial magnetic stimulation (TMS) only.

The effectiveness of the magnetic stimulator is directly related to the amount of generated induced electric field for input current. To design implantable magnetic stimulators, magnetic materials were used to enhance the induced electric field at the stimulus site. High permeable magnetic materials were used to demonstrate a contact-less in-vitro magnetic stimulation for the peripheral nerves based on toroid coil (Ross, TBME'94). However, implantation of these coils is still an open challenge due to the shape and the dimensions of the stimulator. For biomedical implants, predicting the field distribution near the stimulus coil is an important step to optimize the design under system constraints. Analytical and empirical models of the magnetic materials are limited to simplified structures and thus can't be included in the optimization step. Thus, a numerical model needs to be developed which accounts for the non-linear permeability of the ferrite (magnetic) core and computes the magnitude and time dependence of the induced electric field.

In this work, a finite difference (FD) based numerical model numerical model is developed to accurately predict the induced electric field waveform due to the magnetic stimulator. Ideally, the ferrite core based coil improves the pulse duration of the induced E-field. However, due to saturation of the core, inductance of the coil changes drastically from its non-saturated value and causes faster decay in induced voltage. Thus a hybrid simulator is developed which can predict the non-linear behavior of the ferrite core based magnetic coil. The presented work develops a 3-D field simulation of solenoid typed magnetic coil along with SPICE solver for the pulse discharge circuit. Five coils with different dimensions are fabricated and stimulated using a magnetic stimulator. The developed numerical solver accurately predicts the amplitude and waveform of the induced E-field. Measurement and simulation results are within 5% difference with each other. The developed simulator can also predict the effects of the initial voltage of the capacitor on the induced field intensity and saturation time which is useful to define an optimum operating voltage for the given magnetic coil.