Remotely measuring induced radiofrequency currents on wires in MRI

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Introduction: The utility of catheters containing long conducting structures for providing rich diagnostic and guiding information during various percutaneous procedures under MRI has motivated investigation into their safety [1-3]. The electric field associated with transmit RF can induce strong currents on a conductive catheter device which can lead to dangerous heating, typically at the catheter tip. The nature of this heating as well as methods to minimize it are typically investigated using a fiber optic temperature probe and a long scan to induce heating. While specific, this technique is slow and inflexible and cannot easily investigate different devices and/or configurations. Furthermore, this technique can never be applied in a patient because it relies on detecting temperature rises instead of predicting them. The main purpose of this study is to demonstrate a fast, non-invasive method of measuring RF-induced current on conductive wires using an artifact in a phase image acquired from an external imaging coil. The presented technique is more rapid and can be applied more safely than existing measurements relying on magnitude image information (ref). Agreement with a methods-of-moments simulation is presented.

Figure 1: Photograph of experiment setup for the first experiment. The wire can be seen lying on the table in the bottom portion of the image. The PAA phantom lying on the MR table is seen in the upper portion of the picture.

Methods: The underlying principle of this method is that an RF-induced current will generate a secondary magnetic field at the Larmor frequency. This secondary magnetic field causes an artifact in both the phase and magnitude of the true signal. The extent of the artifact is directly related to the current magnitude and thus can be analyzed to measure a current. The current was determined by fitting a measured phase artifact, minimizing the sum of squared residuals between the measured artifact and a simulated theoretical artifact.

The purpose of this investigation was to characterize the current distribution induced along a copper wire during MRI. Two experiments were performed: one simulating a simple percutaneous intervention with a wire parallel to the static field and another with a wire oriented at ~17° to the static field. In both experiments, a rectangular phantom filled with Poly-Acrylic Acid (PAA) gel was used with a wire fully or partially inserted. This phantom was placed in the left-right center of the table of a 1.5T GE Signa EXCITE system (GE Healthcare, Milwaukee, WI, USA) with the bottom surface 9.5 cm below the isocentre. In the first experiment a thin, 420 *μm* diameter copper magnet wire was placed 10 cm to the left and 5 cm below the isocentre with 28 cm (□ λ/2) immersed in PAA and the remaining 72 cm lying along the table, as seen in figure 1. In the second experiment, a wire of total length 28 cm was fully immersed in PAA and oriented at ~17° to the static field. The same SPGR sequence (TE/TR = 10/100, FA=10°, FOV=20cm, slice = 1.5mm, 256x256) was used to measure current in both experiments. Simulations using FEKO (EMSS, South Africa) were used for comparison to experiment.

Results & Discussion: Figure 2 (check caption…looks wrong) shows an example of a measured phase artifact along with a simulated artifact generated using the measured current. This artifact was acquired during the first experiment at a location 17 cm from the wire tip. The measured and calculated images presented in figures 2(a) & 2(b) are virtually indistinguishable save for noise in the acquired image and a small strip of phase-wrap at the top. During analysis, it was qualitatively observed that every fit accurately represented the measured image. Figure 3 displays the comparison of measured current values and simulated values, Induced current values determined through simulation and measured with the presented technique agree quite well. There is a slight systematic error apparent in results from both experiments. This is likely due to disagreement between the prescribed and true flip angle, which could be calibrated and incorporated into any experimental uncertainty on a system-by-system basis. This method improves on existing techniques in two main areas. Firstly, existing magnitude based methods require a lengthy B_1 mapping phase. This technique requires a single scan which allows for very rapid execution of the measurement. Furthermore, this measurement can be performed with a low flip angle, reducing the amount of RF power applied during the measurement and therefore the risk of heating being caused by the measurement. Currently this technique is only applicable in vitro but with further work could be applied in vivo to regularly monitor for unsafe conditions during a procedure.

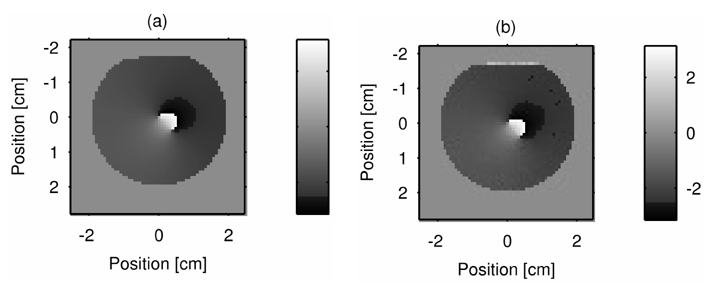

Figure 1: Example of measured phase artifact (b) beside a simulated phase artifact following a current measurement (a). Greyscale is in radians.

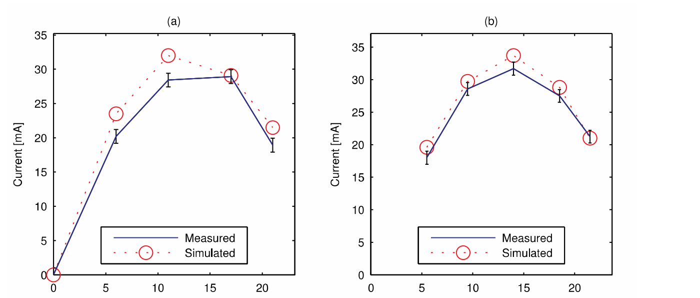

Figure 2: Comparison of the current measurements in the first experiment (a) and the second experiment (b). Error bars were determined directly by a fit termination criterion and positions are relative to the distal wire tip.

Conclusions: A method of non-invasively measuring RF-induced current based on MRI phase artifacts is presented. Phantom experiments were performed and compared with electromagnetic method-of-moment simulations. The promising initial results support further development toward in-vivo applications.

References: [1] Anderson K. MRM 2008;60:489 [2] van den Bosch M. Med. Phys. 2010;37:814 [3] Nordbeck P. MRM 2009;61:570