Sensing of Birdcage Rung Currents for Detection of Anomalous Loading

Christopher Ellenor[1], Pascal Stang[1,2], John Pauly[1], and Greig Scott[1]
[1]*Electrical Engineering, Stanford University, Stanford, CA, United States,* [2]*Procyon Engineering, San Jose, CA, United States*

Introduction. A primary source of risk to the MRI subject is interaction with the radiofrequency fields. Typically transmitted by a birdcage coil, well-known hazards include the coupling of the coil to implanted or interventional wires, and capacitive coupling to tissue of a patient touching the bore surface. Both have been known to cause severe burns. It has also been shown [1,2] that by monitoring the impedance spectrum of the birdcage coil at its drive port, characteristic features appear which are indicative of resonant coupling. Here we propose a new measurement, which can be performed quickly and at low power, wherein we measure the current flowing on each rung of the birdcage coil. Information contained in the spatial current distribution would not necessarily be available at the drive port, and may be indicative of anomalous loading conditions.

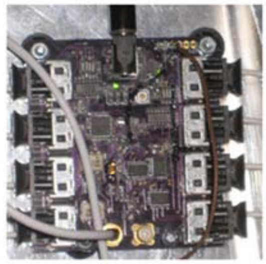

Figure 2 - Reciever unit contains 8:1 RF multiplexer, trigger input, 8-bit microcontroller, 2 amplification stages

Methods. In order to dynamically determine the current flowing in each rung of the birdcage coil, the individual rungs have been instrumented with optically coupled current sensors (Figure 1). The sensors are based on the slotted planar coil current sensors described in [1], which implement a 1:1 transformer in a 4-layer PCB. The output of the transformer is capacitively coupled to a biased photodiode (Firecomms FC300T), outputting the RF-modulated signal over plastic optical fiber (POF). The circuit is powered by a non-magnetic LiPo battery, and includes a battery-charging IC. The receive circuit includes 8 optical receivers (Figure 2) and RF multiplexers which select and output the signal to a transimpedance amplifier, which is followed by a variable gain amplifier and a Medusa console. The multiplexing and gain control is managed by a microcontroller, and a different rung sensor is interrogated on each TR. Current and image data are obtained concurrently.

To calibrate the sensors, a hose phantom containing a saline solution is wrapped around the outer diameter of the coil to facilitate B1 mapping in the vicinity of the rungs. A double-angle field map is created (Figure 3, TR = 1500ms, FOV = 50.8cm) and a contour is drawn around the rung, in a region where the flip angle is close to 45 degrees. Since there is only signal on one side of the rung, the full integral is estimated assuming a symmetric profile.

To test the effects of loading on the pattern of rung currents, a rotatable phantom was constructed, comprising a 1.9 L bottle of saline solution and optionally a wire phantom, which is a wire in a tubular structure, also filled with saline solution.

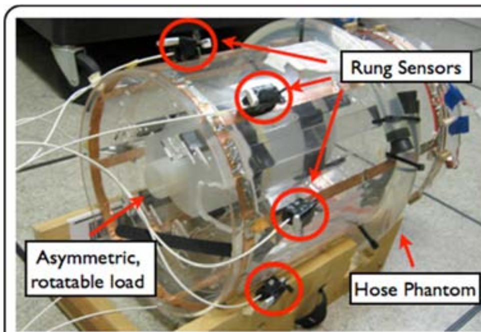

Figure 1 - Modified birdcage - a linearly polarized, single-drive birdcage coil is equipped with 8 optical current sensors. A rotatable plastic mount holds a saline bottle and/or wire phantom off-center. A hose phantom is wrapped around the coil for current estimation in the rungs through B1 mapping.

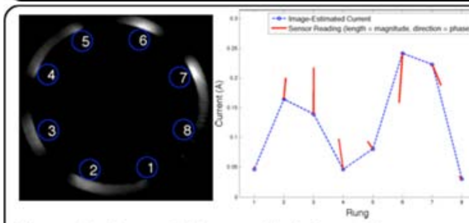

Figure 3 - Sensor Calibration. The left panel shows an image of the hose phantom. The B1 field was mapped using the double angle method, and the current estimated using Ampere's law. The right panel shows the image-estimated current in blue, and the raw sensor data in red, where the length of the line indicates magnitude, and the direction phase.

Results. Figure 3 shows the result of the sensor calibration. The dashed line shows the currents estimated from the image, and the solid lines indicate the magnitude (length) and phase (direction) of the sensor measurements. Even without calibration, the sensor readings show a rough correspondence in magnitude to image-estimated currents. Currents in rungs 1 and 8 were too small to be measured accurately by the imaging method and calibration coefficients were estimated by averaging coefficients of other rungs. As expected, the phase of the current on opposite sides of the coil is opposite. Figure 4 shows the currents measured on the rungs of a coil loaded by the bottle and wire phantom. The dominant effect is a uniform reduction in rung currents, to be expected from coil loading. A distortion in the current pattern is observed, however, when the wire phantom is close to rungs carrying a high current.

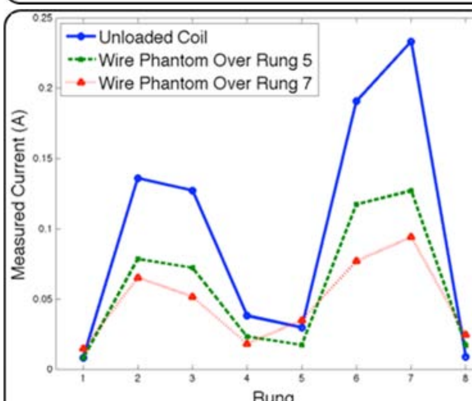

Figure 4 - Results of loading the coil. Loading with just the bottle phantom results in a uniform reduction in current, whereas the resonant wire phantom (wire + bottle) produces a visible change in the current pattern when the wire is near rungs with large currents.

Discussion and Conclusions. Observed deviations in the current pattern were found to be small but distinct. Further work could be done with a broader range of loads to identify characteristic distortions, including in higher field systems where effects should be more pronounced. In addition, these measurements could be used as an aid in B1 estimaton and shimming schemes.

References. [1] Stang et al., Proc. 18th ISMRM, p44, 2010 [2] Ellenor et al., ISMRM Safety Workshop, 2012. NIH Grant Support: R01EB008108, R33CA118276, R21EB007715, P01CA159992.