MRI with a rapidly Rotating RF Coil

A. Trakic[1], E. Weber[1], B. K. Li[1], H. Wang[1], and S. Crozier[1]

[1]The School of Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Queensland, Australia

Introduction: Presented is a new approach for nuclear spin excitation and MR signal acquisition using rapid rotation of a single RF transceive coil about a patient. Rotation of a RF coil offers a new degree of freedom for MR imaging in that it emulates a RF coil array in a fashion akin to time-division-multiplexing. A rotating RF transceive coil system for head imaging at 2 Tesla was constructed and the images acquired were of good quality. The rotating RF coil approach obviates the need for multiple channels and intricate RF decoupling of many stationary coils.

Methods: The frequency of both the RF transmission field and the resonating ^{1}H nuclear spin (i.e. tens to hundreds of MHz) is six orders of magnitude larger than the frequency of a rotating RF coil (i.e. tens to hundreds of Hz). Therefore, in the temporal frame of reference of the RF transmission field and the nuclear spin, the rotating RF coil can be perceived as 'physically stationary' while the spin system is excited and the MR signal is induced in the RF coil. Fig 1 illustrates a single RF coil that rotates around the subject at the angular frequency $\omega_{coil} = \theta_{coil} / t$. At any point in time of one coil revolution, the rotating RF coil creates a spatially unique field profile $\mathbf{s}_\theta(\mathbf{r}) \equiv \mathbf{s}_{\omega t}(\mathbf{r})$ as a function of θ_{coil}. In effect, as the net magnetization is tipped into the transverse plane or the MR signal decays, a fast rotating RF transceive coil can be perceived as multiple stationary coils analogous to a conventional *N*-element RF transceive array. In contrast to the standard expressions for net magnetization excitation $\mathbf{M}_{exc}(\mathbf{r})$ and MR signal $\mathbf{S}(t)$ detection, the rotating RF coil adds a new degree of freedom for the manipulation of the spin, signified by the subscript ωt in the weighting (filter) function $\mathbf{s}_{\omega t}(\mathbf{r})$:

Transmission: $$\mathbf{M}_{exc}(\mathbf{r}) = i\gamma \int_{T_b} \mathbf{b}_1(t)\mathbf{s}_{\omega t}(\mathbf{r})\mathbf{M}_0(\mathbf{r})dt \quad (1)$$

Reception: $$\mathbf{S}(t) = \mathbf{S}(\mathbf{k}(t)) = \int_R \mathbf{s}_{\omega t}(\mathbf{r})\mathbf{M}_{exc}(\mathbf{r},t)e^{-2\pi i \mathbf{k}(t)\cdot\mathbf{r}}d\mathbf{r} \quad (2)$$

where $\mathbf{b}_1(t)$ is the RF pulse, $\mathbf{k}(t)$ represents the k-space trajectory, $\mathbf{M}_0$ is the initial magnetization, γ is the gyromagnetic ratio, T_b is the RF pulse length and $\mathbf{r}$ denotes the position vector. When Eqs.(1) and (2) are written in discrete forms to comply with the MR digital instrumentation, in one period of revolution, the rotating RF coil emulates $N=2\pi f_s/\omega_{coil}$ virtual stationary coils, where f_s is the sampling frequency of the RF coil signal. A rotating RF transceive coil system for head imaging, as shown in Fig. 2, was implemented for use in a 2 Tesla whole-body MRI system (CMR, University of Queensland, Australia). A custom-designed, pneumatic Tesla turbine (*1*) with ceramic bearings was used to rotate a Ø280mm transceive RF coil. A second, fixed concentric Ø260mm cylinder then acted as the head holder. A Ø340mm RF shield reduced power losses and a frictionless inductively-coupled RF link connected the rotating transceive coil to the MRI system. A constant rotational speed of the coil was governed by the air pressure drive to the Tesla turbine and measured with an infrared photo-interrupter. This scheme constituted an open-loop system and the observed maximum rotational speed was about 870rpm at 35psi after the rotating structure was mechanically balanced.

Results and Discussion: Figs.3 and 4 show head images of a 34 year old male obtained with the rotating RF system operating at a speed of approximately 480rpm and 600rpm, respectively. The results exemplify complete images of good uniformity and well-resolved anatomical brain structures in all three Cartesian planes. Considering the FLASH sequence parameters, f_s=50kHz, speed of 480rpm and $N=2\pi f_s/\omega_{coil}$, we estimated that in this experiment the continuously rotating RF coil has produced around 1182 RF coil sensitivity profiles.

Conclusion: The experimental results suggest that a single rotating RF coil can emulate a conventional multi-element array. The benefits of such a scheme are that coil coupling interactions and the requirement for multiple signal pathways cease to be a practical impediment. We are currently developing MRI techniques for accelerated imaging that exploit the principle of array emulation and optimal trajectories in polar k-space.

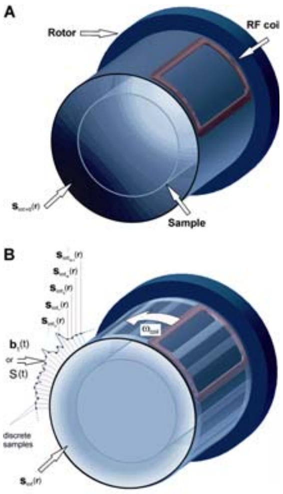

Fig. 1. Illustration of a RF transceive coil attached to a rotor. **(A)** The RF coil is stationary relative to the subject (i.e. ω_{coil}=0); **(B)** The RF coil is rotating around the subject at the angular frequency ω_{coil}. As $\mathbf{b}_1(t)$ is pulsed or $\mathbf{S}(t)$ is sampled during one period of revolution, each discrete signal sample relates to a unique $\mathbf{s}_\theta(\mathbf{r}) \equiv \mathbf{s}_{\omega t}(\mathbf{r})$ produced by the coil.

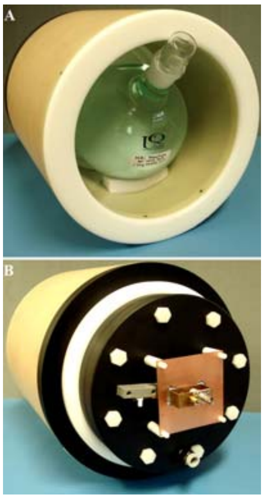

Fig. 2. (A) Front view of the rotating RF coil system for head imaging measuring approximately 340mm in diameter and 480mm in length; **(B)** Rear view showing the inductively coupled RF link. The rotating RF transceive coil is residing between the RF shield and subject holding cylinders.

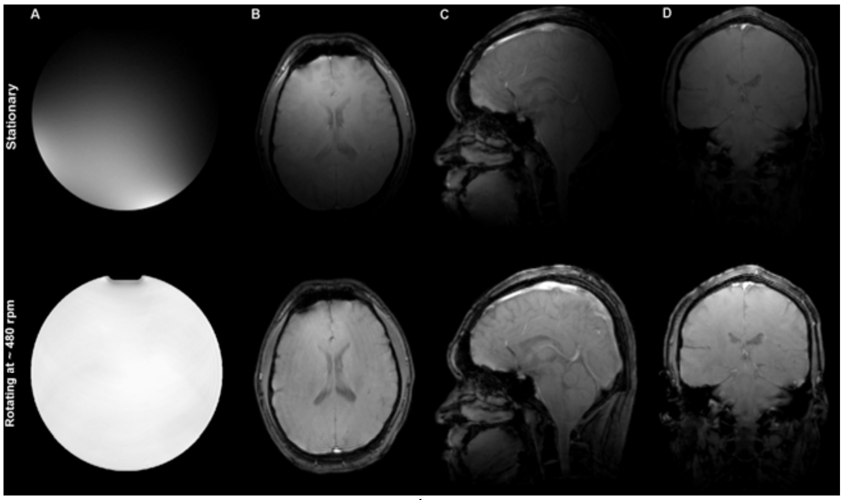

Fig. 3. T_1 weighted MR images of: **(A)** A homogeneous Ø200mm saline-based spherical phantom and **(B-D)** Head images in axial, sagittal and coronal planes, respectively. The top row images shows were obtained when the RF transceive coil was fixed to one side of the subject prior to spinning it. In this case, the RF coil can 'see' only part of the subject due to its limited field of view (FOV). In contrast, bottom row shows complete images of the spherical phantom and the head when the RF coil was rotating at a constant speed of 480rpm (i.e. ~ 50.27rads^{-1}). The Fast Low Angle Shot (FLASH) sequence parameters were as follows: time of repetition (TR) of 176ms, slice thickness (ST) of 5mm, FOV of 30 x 30cm, matrix size of 256 x 512 and flip angle (FA) of 90°.

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References:

1. N.Tesla, *U.S.Patents 1,061,206*, 1911

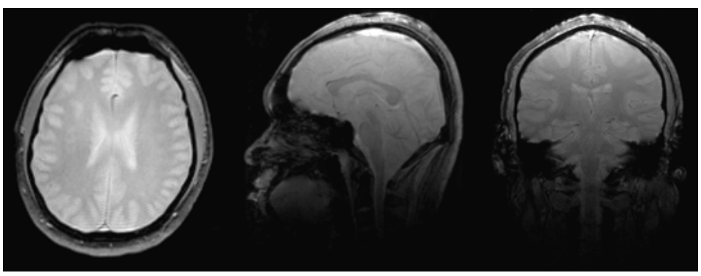

Fig.4. Axial, sagittal and coronal head images obtained by operating the rotating RF system at 600rpm and using following FLASH pulse sequence parameters: TR=158ms, ST=5mm, FOV=30 x 30cm, matrix size of 256 x 512 FA=45°.