A Cosine Wire Coil Based on Litz Concept

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Introduction
It is known that the relationship between a cylindrical surface current density \( \mathbf{J}(\phi) \) and a desired magnetic field \( \mathbf{B}_1 \) in the cylinder is expressed by [1]

\[
\mathbf{J}(\phi) \propto \mathbf{B}_1 \cos(\phi) \cdot \mathbf{k}
\]

where \( \phi \) denotes the azimuth, \( \mathbf{k} \) is the unit vector along the cylinder axis. Obviously if the current distribution is the cosine function of azimuth, \( \mathbf{B}_1 \) is homogeneous. Birdcage resonators widely used in NMR realize the discretely approximate cosine distribution where the conductors are uniformly mounted on the cylinder surface. Ref.[1] points out another way to generate homogeneous field, where all conductors are assumed to have approximately equal current, but wire positions are decided by projecting the intervals of equal length along the diameter onto the circumference. This coil is called cosine coil [1]. In this paper, expecting better uniformity, we import Litz concept from [2] to constructing a cosine coil. The coil performance is tested by SNR and homogeneity analysis of phantom images.

Methods
Our basic cosine structure design has 16 conductors (legs) parallel to the cylinder axis. Suppose the legs are 40 millimeters (mm) long. The magnetic field is approximately calculated by Biot-Savart law and the field strength comparative deviation from center field is shown in fig.1. The good homogeneity is easily seen.

The first core construction for approximate realization of the current distribution is shown schematically in fig. 2.1. The red indicates the capacitors and the blue denotes conductors made of copper foil strips. Its geometry is similar to the 22-leg cosine wire coil of ref.[1,3]. The legs are connected to each other by the copper rings at the two ends. The legs are 2mm wide. The end ring width is 5mm. Because the inductance and resistance in every leg current path are different, the currents are not exactly equal. For a more uniform current distribution, we would try making the current on every leg flow through almost equivalent routes.

The copper strip pattern of the second design is shown in fig. 2.2. Because of symmetry, only one half is given. The yellow bar implies an electrically insulated crossover across which the two conductor groups at the left and the right are switched to the opposite sides, that is, by which the current on the higher impedance leg goes onto the lower impedance leg and vice versa. Eventually legs have more uniform current than those in fig 2.1. Fig. 2.3 is another construction according to center-fed Litz type coil [2], here the end ring is further divided into strips of 2mm width and segments forming new Litz groups. The end ring current is forced to be more uniform, not to be concentrated at end ring edges. Its window height is about 28 mm.

The conductors are mounted on a Teflon tube with a 1.25 inch inner diameter and 1.5 inch outer diameter. Three coil cores use the same shelf and shield of an old commercial coil, are capacitively driven at a capacitor, and are tuned and matched at about 400 MHz for our GE Omega 9.4T vertical bore system. Spin-echo k-space matrices of a phantom are acquired to quantitatively evaluate SNR and homogeneity. A complex valued image \( \hat{f}(i,j) \) is reconstructed by FFT, and its local SNR is estimated by

\[
\text{SNR}(i,j) = \frac{s(i,j) - m / \sigma}{m}
\]

where \( m \) and \( \sigma \) are the background mean and standard deviation respectively. \( s(i,j) \) is the average of 7x7 neighborhood pixels at \( (i,j) \). The background comprises sub-images (size 10x10) at the four corners of an image matrix. In a central specified ROI radius r normalized by FOV, the image homogeneity is evaluated by \( \delta / m_o \) where \( m_o \) is the \( \{f(i,j)\} \) mean and \( \delta \) denotes the \( \{|f(i,j)\}\) mean absolute deviation from \( m_o \).

Results and Discussion
The 21ml CuSO4 solution (5mM) in a cylindrical glass bottle with 28mm inner diameter is used as a phantom. Phantom axial images are used for the study. Imaging parameters are as follow: TR=500ms,TE=18ms, FOV=40mm, 2 acquisitions, 8 slices, 3mm slice separation, 1mm slice thickness, 0 slice offset, 256x128 k-space matrix (extended by zero-filling to 256x256 before FFT). Power levels and gains are optimally decided by system software.

The max SNRs of slice images from the three coil cores of fig 2 are 94±8 (mean ± standard deviation), 94±10 and 85±8 respectively. Here SNR is directly defined by complex images, but \( \text{SNR} \cdot \sqrt{2} \) results in the common signal-noise-ratio of an amplitude image assuming that the real noise and the imaginary noise independently are zero mean white Gauss and that they have the same power.

The homogeneity as a function of ROI normalized size is shown in fig.3, where homogeneity improvement of images from Litz type coil is observable.

The first two cores are more easily fixed and fed from the edge than the third one in our small bore magnet. Center-fed may easily bring image distortion. Fig 4 displays a mouse body axial image by using the second coil core, which looks quite good.

References