Design of compact planar GC for high field open MRI using the computational tool DUCAS

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Introduction

The computer code DUCAS [1] has been developed as a coil and magnet design tool for nuclear fusion research. It has the capability to obtain a current distribution on an arbitrarily shaped surface so as to reconstruct a given magnetic field distribution. In this presentation, the code is applied to the gradient field coil (GC) design with the objective of designing a practical planar actively shielded GC (ASGC) for an open high-field MRI system. Such a high field MRI magnet can be large. The GC size may have to be made large to get a strong gradient field; in turn, the large GC enlarges the magnet size. To reduce the overall size, we introduced a design technique using DUCAS to design a compact ASGC and to reduce the leakage magnetic field around the GC.

Computational Technique and design of ASGC

DUCAS can treat arbitral surfaces using triangular finite elements, by calculating current potentials T on the nodes [2]. Thousands of node T values describe the T distribution on a surface, and the vector product of the normal vector $\boldsymbol{n}$ on the surface and the gradient of T, gives the current density vector [2]. DUCAS calculates the T-distribution to get the target magnetic field distribution. The T-distribution forms a vector $\boldsymbol{T}$ and the target magnetic field distribution forms a vector $\boldsymbol{B}$. The relation between them can be written as $\boldsymbol{B}=\mathbf{A}\boldsymbol{T}$, where $\mathbf{A}$ is a response matrix. The pseudo-inverse matrix $\mathbf{A}^*$ is calculated through singular value decomposition and $\mathbf{A}^*\boldsymbol{B}$ gives a reconstructed T-distribution. Coil conductors are placed on the contour lines of the obtained T on the surface, to generate the target magnetic field distribution. The capability of DUCAS to treat arbitral surface, supports the design of the ASGC.

The Original DUCAS code can treat a single surface, but it was modified to treat plural surfaces by introducing an iterative calculation [3]. At first, a simple two-plane type ASGC [4] was tried. Coil patterns of the main and shield coils were calculated to produce the gradient field on the field of view volume and to shield the magnetic field toward the normal direction of the coil plane. However, it was concluded that this type of ASGC was not applicable, because of the leakage field in the radial direction and the high current density in the compact ASGC.

Then we introduced two ideas: (1) use of a direct connection between the main and shield coils to remove return conductors and to reduce size of the ASGC; and (2) use of a curved surface for the shield coil (umbrella shape) to bend the magnetic force lines. Fig.1 shows the computational geometry (left) and the calculated pattern of the Y-GC (right). CCS1 is the current carrying surface for the main coil and CCS2 is that for the shield coil. The gradient field was evaluated on the surface MFES1, and the leakage magnetic field on the MFES2 was managed to be zero. Our first idea allows compact GC to be made, because some return conductors are removed, which means that some of the conductors generating the leakage field are eliminated. This idea also leads to the desirable result that translational force on the GC can be neutralized due to reduction of the undesirable leakage field. According to our second idea, the surface CCS2 is deformed to wrap around the surface CCS1, giving it a capability to shield the magnetic field toward the radial direction. This results in a reduction of the eddy currents on the magnet structures.

Results

The ASGC in Fig.1 is a practical GC, with a capability of 33mT/m gradient field generation and a compact radius of 1m. Fig.2 shows the magnetic field on the Y-Z plane. The static field is in the Z-direction. Around the field of view area, the vertical field strength Bz distribution of the coil is plotted with contours of 1mT/line. On other areas, strength of the magnetic field is plotted with 1mT/line contours. The numbers in the figure are magnetic field strength in mT unit and the arrows are magnetic field vectors. In the area Y>0.5m, magnetic field is weak as expected. At the top area of the figure, the vectors are very short, meaning that a good self-shield effect is obtained. We conclude this ASGC can be used as planar ASGC for high-field open MRI.

References

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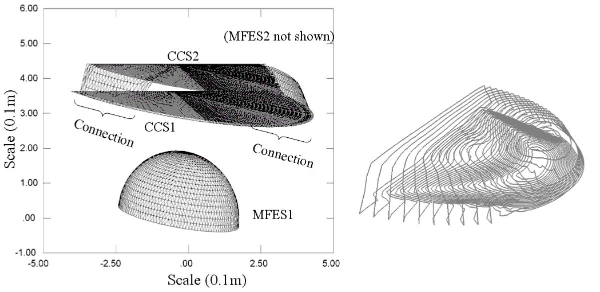

Fig.1 Left; Computational model for active shield Y-GC with a symmetric conditions of $T(Z)=T(-Z)$ and $T(Y)=-T(-Y)$. CC2 is curbed. There are connections between CCS1 and CCS2. Right; Calculated Y-GC pattern some of coil turns are connected between main and shield coils.

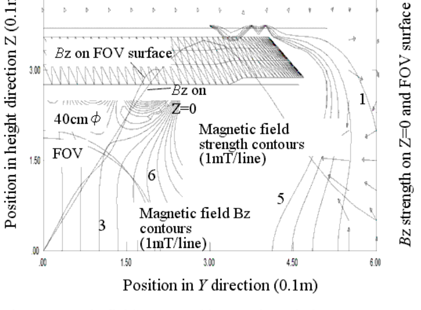

Fig.2 Magnetic field generated by 3D shaped planer Y-GC with active shield.