Low Power and High Field Strength B0 Coil: A Vision of Portable MR

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Abstract

In order to address the need of the MR coil with both high field strength and low power usage, a miniaturized B0 coil is presented. Finite element simulation showed that higher magnetic field strength was generated by a coil with sharp tip than that by a coil with blunt end. A cost effective way was introduced to fabricate this sharp tip coil. Focused magnetic field generated by the coil with a sharp tip was directly measured by a tunneling effect magnetic field sensor. This study will help in addressing the need of portable MR systems.

Introduction

Portable MR is promising in various kinds of applications. Regar et al demonstrated the usefulness of a self-sustained portable MR system through the application of an intracoronary magnetic resonance probe in 2006[1]. However, the field strength of the permanent magnet on this MR probe was limited. Higher field strength is desired for better image quality, narrower bandwidth and faster scan time.

To achieve higher magnetic field strength in the application of spectroscopy, an electromagnet is preferred. Since the power of portable MR is limited, a traditional solenoid coil is inefficient. We chose to use a coil with a ferromagnetic tip to focus the magnetic field therefore generates a high magnetic field using minimal power. The first design of a coil with ferromagnetic tip was demonstrated in magnetic force microscopy by Rugar et al in 1990[2]. In this abstract, after designing the ferromagnetic tip using finite element simulation, direct measurements of the newly designed B0 coil were taken using a tunneling effect magnetic field sensor.

Materials and Methods

A modified method from Mathews et al [3] was used to fabricate our ferromagnetic tip. Pure iron cores (length/diameter/purity = 2”/0.0625”/3N5, ESPI Metals) were covered by heat-shrink tubing with 2 mm gap around one end. Iron cores with tubing were submerged into a solution of 1:1:2 sulfuric acid, phosphoric acid and water, and applied 6V of current for ~25 min until the iron cores broke. Extra 3V was applied for ~1 min for surface finishing. The etched iron tip is shown in Fig 1. The etched iron core was wounded by 400 turns of 44 gauge of copper wire and fixed on the coil holder as the coil unit (Fig 2).

The microscope image of the etched iron core was imported into SolidWorks for 3D modeling, and the CAD was exported to COMSOL 3.5a for finite element simulation. The physics model of magnetostatics was used. The model of copper wire was simplified as thickness/length = 0.3/20 mm copper sheet wrapped outside of the iron core (Fig 3), and current density of 88300 A/m^2, which is equivalent to 1 A current applied on 400 turns of copper wire, was applied on it. Relative permeability of the iron core was set to be 4000. The iron core, etched tip and wire models were placed inside of a cylindrical boundary with diameter/height = 5/40 mm. mesh number of the iron core/etched tip/copper sheet/boundary = 2464/7358/2545/30458.

Coil unit was secured on a 3D translational stage along and operated under a surgical scope (Fig 4). The tunneling-effect magnetic field sensor (STJ-020, sensing area: 2x4 µm, Micro Magnetics) was used to measure the magnetic field (Fig 5). The actual magnetic field was calculated by the following equation

$$V_{out} = V_0 + H \{(S * V_{in} * G_1 * G_2)/[100 * (G_1 + 1)]\},$$

where V_{out} is the output from the pre-amp, V_0 is the residual DC shift after calibration, H is the magnetic flux density, S is the sensor sensitivity and G is the gain on the pre-amp board.

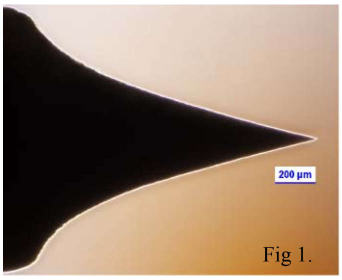

Fig 1.

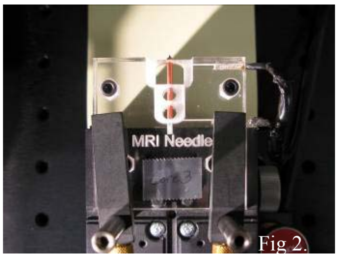

Fig 2.

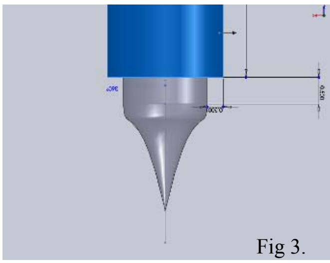

Fig 3.

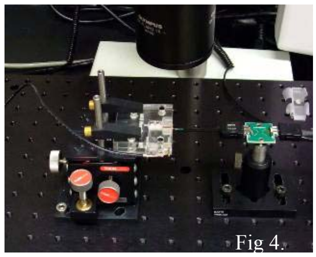

Fig 4.

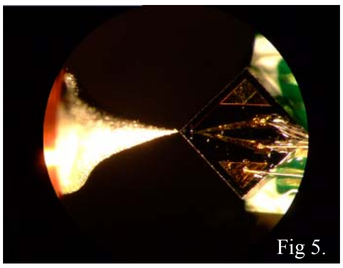

Fig 5.

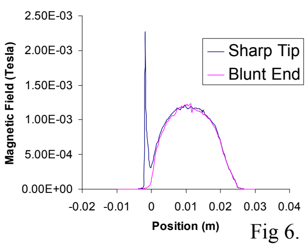

Fig 6.

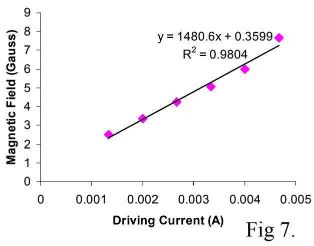

Fig 7.

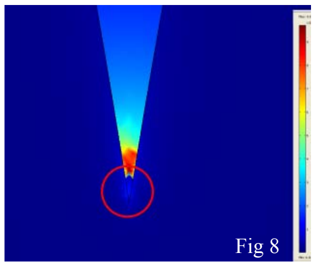

Fig 8

Fig 1. Microscope image of etched iron tip. Fig 2. The coil with the holder on the 3D translation table. Fig 3. Physical model of the coil for finite element simulation. Fig 4 and 5. Coil and STJ-020 sensor under surgical scope. Fig 6. Comparison of the distribution of magnetic field along the coil with sharp/blunt tip. Fig 7. Measured magnetic field out of the B0 coil. Fig 8. Simulated magnetic density flux around the sharp tip.

Results

Finite element simulation showed that a coil with sharp tip has stronger magnetic field strength compared with a blunt tip (Fig 6). Small currents were applied on the coil due to the limited measurable magnetic field strength of the sensor (5-10 Gauss). The measurements are shown on Fig 7. The maximum measurable magnetic field was 7.6 Gauss using the coil with 4.67 mA of current.

Conclusion and Discussion

The magnetic field on the tip area was not successfully solved due to singular matrix problem (Fig 8). Nonetheless, finite element simulation showed that the coil with sharp tip has higher magnetic field strength at the exit of the coil. Under the assumption that the magnetic field generated by the coil is linear and according to the extrapolation of the measured data, the magnetic field of 1.4 Tesla is achievable if 1A current is applied. Localized magnetic field also helps in MR safety for portable MR system. Multi-layer of wires and larger diameter wire can further increase the magnetic field in the future.

Reference

[1] Regar et al, EuroInterv, 2006. [2] Rugar et al, J. Appl. Phys, 1990. [3] Mathews et al, Appl. Phys. Letter, 2004.