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Detecting and Estimating Magnetic Fluid Properties by a Needle- Type GMR Sensor

H. Shirzadfar[1,*], R. Haraszczuk[2], M. Nadi[1], S. Yamada[2], D. Kourtiche[1]

[1] *Electronic Instrumentation Laboratory of Nancy, University of Lorraine,*
EA 3440 – 54500 Nancy, France
[2] *Institute of Nature and Environmental Technology, Kanazawa University,*
Kakumamachi, Kanazawa 920-1192, Ishikawa, Japan

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Magnetic fluid or magnetic liquid are colloidal solutions of ultra-fine magnetic materials. Ferromagnetic materials consist of magnetic or other compound containing iron, nickel or cobalt, by a particle size of 5 to 50 nanometers, generally in a superparamagnetic, ferromagnetic or diamagnetic state. Magnetic fluids have a unique combination of strength and ability to interact with the magnetic field. This paper proposes to estimate and detect magnetic fluid weight density (concentration as low as 1%) by giant magnetoresistance (GMR) sensor. The high sensitivity of the sensor is around 11 μV/μT. We propose to use it for bioapplications to characterize magnetic microfluides. For this application a Helmholtz coil was simulated and fabricated to make more uniform magnetic flux density.

Keywords: GMR Sensor, Magnetic Fluid, Helmholtz Coil, Weight Density, Permeability.

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1. INTRODUCTION

The magnetic fluid consists of a fluid that contains small particles of magnetic materials. Magnetic fluids are unique in that high turnover is combined with high magnetization greater than of ordinary liquids. Each particle is coated with a thin layer of protective membrane that prevents the adhesion of the particles and the thermal motion of the scatters them throughout the entire volume of the liquid [1]. Therefore, in contrast to conventional suspensions of particles in magnetic fluid did not settle to the bottom, and can maintain their performance over many years.

When the magnetic field is applied to the ferrofluid (magnetic fluid) the magnetic moments of the particles orient along the field lines almost instantly.The magnetization of the magnetic fluid responds instantly to changes in the magnetic field, and when the applied field is removed, the random points quickly.

Nowadays, ferrofluids are used in the several consumers and proposed for various applications such as in the medicine (magnetic cell separation, cancer treatment [2], magnetic drug delivery and etc.), in mechanical engineering, electronic devices, mining industry and military.

Identification of small molecules is biomolecular expertise, so these new and exciting ways to build ahead of the specific sensors. The fabrication micro-sensors are the great goal for investigations and developing in biomedical applications [3]. GMR sensor is a sensor of this type by high sensitivity and detection capability for measurement in small fields [4].

The aim of this research is to propose a novel needle-type gain magnetoresistance (GMR) sensor which has a good ability to estimate the magnetic flux weight density (D_w) even with low concentration.

2. SV-GMR NEEDLE SENSOR

The needle type SV-GMR sensor consists of two GMR sensing elements, the first sensing element (GMR1) at the tip of the needle and the second sensing element (GMR2) at the end of the needle, the two sensing elements are connected in a Wheatstone bridge configuration [5]. The needle-type GMR sensor is shown in Fig. 1.

The needle is made of a hard material such as Aluminum Titanium Carbide (AlTiC), and compound materials of Aluminum Oxide and Titanium Carbide (Al_2O_3/TiC). The needle length equal 30 mm by cross section 300×300 μm is available to insert to midpoint of container for determination and estimation ferrofluids. The needle probe sensitivity is approximately 11 μV/μT. The dimension of each sensing elements (2 GMR) are 40 μm per 40 μm.

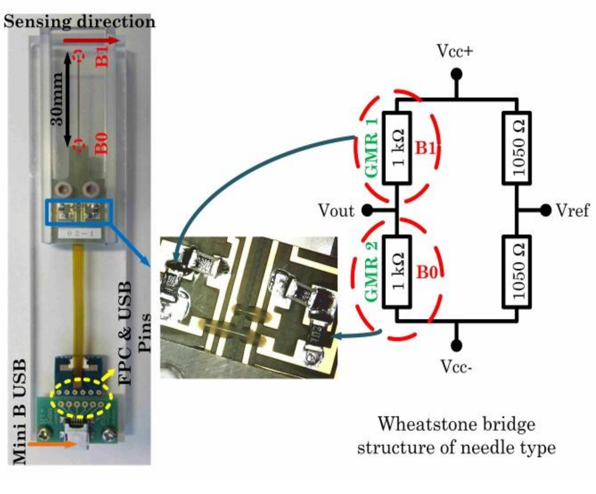

Fig. 1- SV-GMR sensor

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[*] Hamidreza.shirzadfar@univ-lorraine.fr

3. LOW-CONCENTRATION MAGNETIC FLUID CONTENT DENSITY DETERMINATION

The shape of the magnetic nanoparticles is presumed to be cylindrical with a uniform distribution in the fluid.

Magnetic nanoparticles show paramagnetic behavior if their relative permeability $\mu^* > 1$, and diamagnetic behavior if $\mu^* < 1$. The relative permeability, μ^*, of magnetic fluid is estimated as,

$$\mu^* = 1+4D_w \approx h_s\gamma_f \quad (D_w \ll 1) \qquad (1)$$

Where D_w is magnetic fluid weight density (gFe/ml), the specific gravity of magnetic bead γ_f is 4.58, and the space factor of cluster h_s is 0.523 [6].

The magnetic fluid weight density can be calculated from the difference between the applied magnetic flux density, B_0, and the magnetic flux density, B_1, inside the fluid filed cavity.

Fig. 2, Shows a distribution of the magnetic flux density inside (which is assumed μ^* more than 1) and outside (assuming $\mu^*=1$) of ellipsoidal cavity. The equation 2 gives the relationship between changes magnetic flux density δ and magnetic fluid weight density D_w.

$$\delta = (B_1 - B_0)/B_0 = C_d(1-N)D_w/h_s\gamma_f \quad (D_w \ll 1), \qquad (2)$$

where B_0 is the applied magnetic flux density outside and also B_1 is the magnetic flux density inside the cavity, C_d is a coefficient which is theoretically 4, N is demagnetizing factor (for spherical shaped cavities s = 1 and N = 0,333.) [2].

The relationship of relative susceptibility (χ^*) and the ratio of magnetic field (δ) detected by the GMR sensor is calculated by:

$$\delta = (B_1 - B_0)/B_0 = (1 - N)\chi^* \quad (\chi^* \ll 1) \qquad (3)$$

The magnetic fields B_1 and B_0 are in cavity and in free area respectively [5].

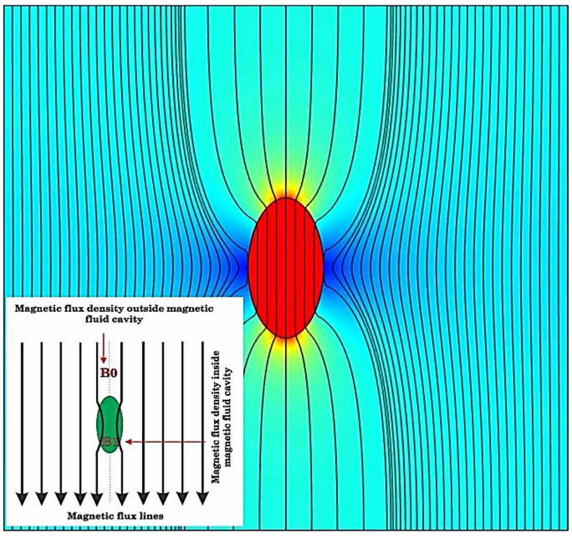

Fig. 2 – Magnetic flux density distribution inside and outside of ellipsoidal cavity

4. HELMHOLTZ COIL AND UNIFORM MAGNETIC FLUX DENSITY

In this experiment for measurement and determination ferrofluids by SV-GMR sensor we recommended to utilized Helmholtz coil as shown in Fig. 3.

Helmholtz coil is ideal for producing a large area of uniform magnetic field. It should be noted that the magnetic field range for measurement by SV-GMR sensor is between 5nT to 1mT.

A homemade Helmholtz coil was designed and fabricated consist of two coils by diameter 0.25 meters, the coil radius is equal to the distance between two coils by each coil 106 turns.

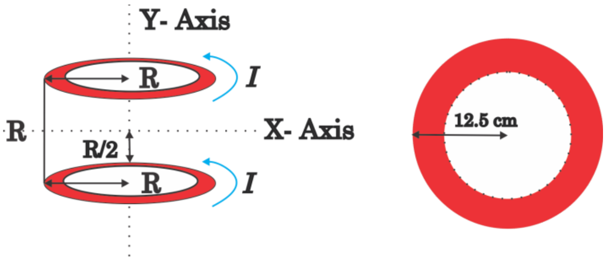

Fig. 3 – Helmholtz coil structure

One constraint before proceeding to experimental measurement on magnetic fluids is to set the value of the magnetic field not too high in order to maintain sensors safety. For this reason, simulations using COMSOL were done to dimension the values of the magnetic field. The total distribution of magnetic flux density (mT) in the area of Helmholtz coil is shown in Fig. 4.

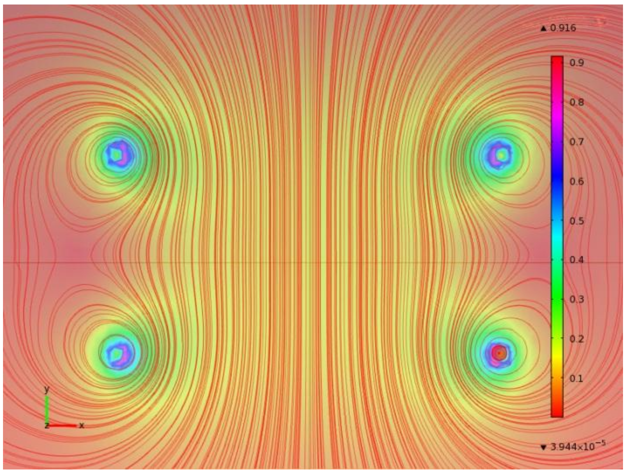

Fig. 4 – Distribution of magnetic flux density (mT) in the center and around of Helmholtz coil

For calculation the magnetic flux density (T) and magnetic field (A/m) of Helmholtz coil by COMSOL, need to specify the dimensions of Helmholtz coil (R, m), input current (I, A), number of wire loops and wire cross section.

In the simulation by COMSOL need to be attention for select the correct equation of magnetic field for external current density and direction of current (x, y, z) according to Helmholtz coil position (vertical and horizontal).

Figs. 5-6 present the 3D simulation plot and distribution of magnetic flux density (T) inside the coil. As can be seen in Fig. 6, by approaching the arrows to the center of Helmholtz coil the uniform magnetic field considerably increases.

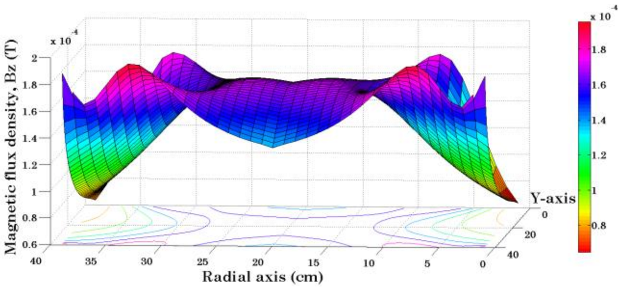

Fig. 5 – Calculated axial component of the magnetic flux density

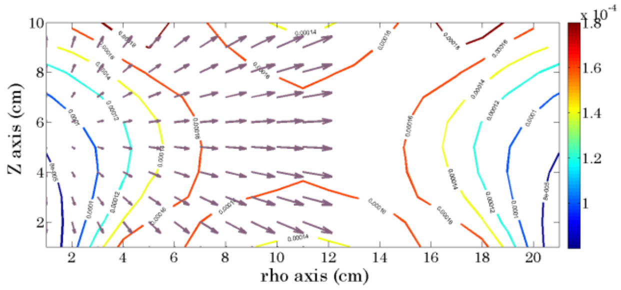

Fig. 6 – Distribution of magnetic flux density in sphere of coils

5. EXPERIMENTAL SETUP AND RESULTS

Experiments were performed to prepare four different magnetic fluids with several weight density (D_w).

In this experiment the magnetic fluid is diluted in distilled water to achieve weight densities at respectively 0.09%, 0.3%, 0.4% and 1% as shown inFig. 7. To create the magnetic fluid by different weight density, pure magnetic fluid (Fe_2O_3) was used, the concentration of pure magnetic fluid is 40 % magnetic fluid and 60 % distilled water by particle size 16 nm.

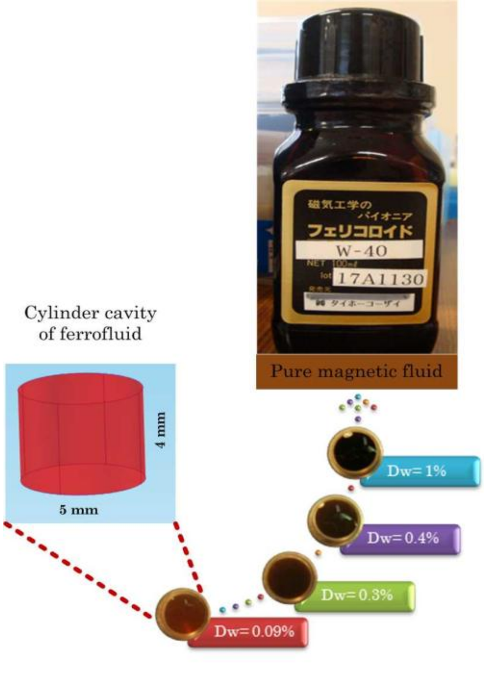

Fig. 7 – Top-view model of four different weight density of magnetic fluid

The 0.0785 ml of magnetic fluid was poured by pipette in cylindrical shape cavity of 5×4 mm. After the four ferrofluids having been prepared in four containers they were placed at the midpoint of the coil, where the magnetic field is the most uniform.

The used experimental setup is presented in Fig. 8. Experiments were performed with the needle-type SV-GMR sensor to characterize the four samples (weight densities varying from 1 %, 0.4%, 0.3% to 0.09%) of magnetic fluid. The sensor needle was precautionary placed inside the ferrofluid at the center of the tank. The probe SV-GMR is connected to Dc power source (± 6 V), the output signal is amplified by use of an amplifier circuit (Analog Devices AD 524). The differential signal Vout-Vref of the whole sensor and its conditioning electronics was supplied to a multifunction Digital Lock-in Amplifier (NF Li 5640).

Data of the lock-in amplifier (values of amplitude and phase) were collected and treated under MATLAB®.

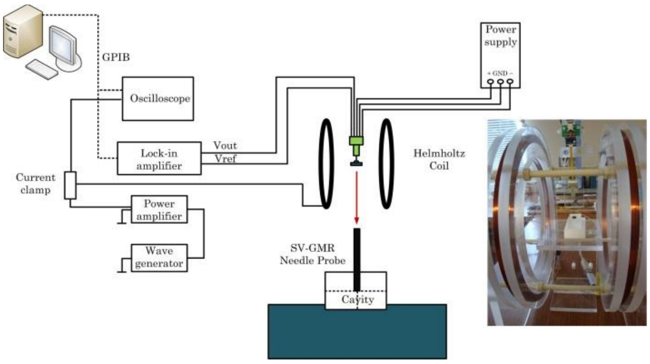

Fig. 8 – Experimental and measurement setup

Helmholtz coil amplified by a power amplifier and was powered by a sinusoidal signal from the wave generator (Wave factory 1965 NF electronic instruments multifunction), the amplitude of Helmholtz coil observed by oscilloscope (Iwatsu DS-8814 Bringo Oscilloscope).

The experiment frequency of exciting field of the Helmholtz coil is 100 Hz, the input current of the coil is 200 mA, exciting field (H) is 121 (A/m) and magnetic flux density is 1.53×10^{-4} T.

Fig. 9 presents the results of relationships between relative permeability and susceptibility depending on weight density obtained by needle type GMR sensor and compared with results achieved from measurement by vibrating sample magnetometer (VSM). It can also be seen that μ_r and χ are proportional to D_w.

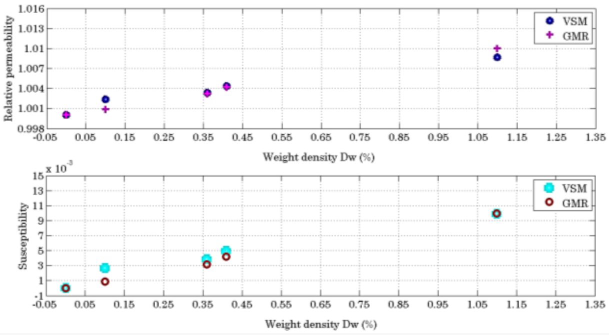

Fig. 9 – Relative permeability and susceptibility versus weight density (%) results compared for GMR and VSM

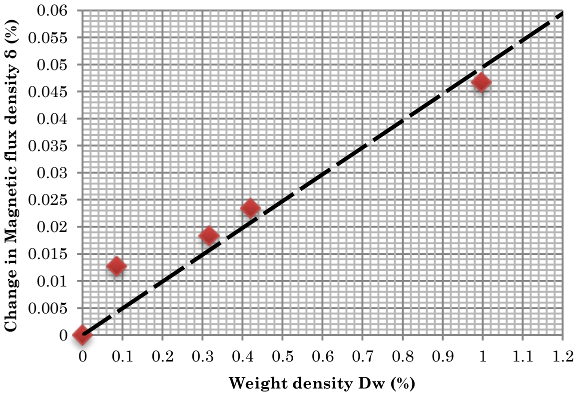

Fig. 10 – Estimation the change magnetic fluid density with different weight densities

VSM refers to a technique for measuring magnetic fields and can be used to determine the magnetic properties of substances and materials in the laboratory and experimental devices.

The GMR needle probe was used to estimate the D_w of the magnetic fluid, by measuring the applied magnetics flux density outside (B_0 = 152.5 μT) and the magnetic flux density inside (B_1) of cavities.

The demagnetizing factor (N) depends on the shape ratio of the cavity (s), cavity in thin and long type the demagnetizing factor is zero (N = 0, S = ∞) [7].

The experimental results are performed to estimate magnetic flux density (δ) by increases weight density (D_w) with shape ratio of cavity (s = 1 and N = 0,333 for ellipsoidal shape) and shown in Fig. 10. The experimental results show that D_w is proportional to magnetic flux density variations.

6. CONCLUSION

SV-GMR sensor being used to estimate low concentration magnetic fluid, its high sensitivity (11 μV / μT) allows to detect and estimate magnetic properties of fine nanofluid particles.

The experimental results achieved in this research show a proportional relationship between relative permeability, magnetic flux density, susceptibility (in the range 0.01 to 0.001). Changes of weight density for the four samples have good correlation for the results obtained by SV-GMR sensor and VSM.

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