Development of A Compact and Sensitive AC Magnetometer for Evaluation Of Magnetic Nanoparticles Solution

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***Abstract*— A compact and sensitive AC magnetometer is developed for evaluation of magnetic nanoparticles solution. The developed AC magnetometer consists of two main parts; excitation and detection coil systems. A Helmholtz coil configuration was used as the excitation coil to ensure a high homogeneity of excitation magnetic field. To reduce AC resistance due to eddy current effect in the wire of the excitation coil at a high-frequency region, a Litz wire was used. The Litz wire was composed of 60 strands of copper wires with 0.1-mm diameter. For the detection coil, a first order axial differential coil was used so that environmental noises can be canceled. The detection coil consisted of two 1000-turn copper coils and they were connected in series. The fabricated excitation coil showed a high homogeneity along its axis with the high excitation magnetic field. The sensitivity of the developed system increased with respect to frequency. The magnetic noise of the detection unit showed a 1/*f* noise characteristic and a sensitivity of 10^{-10} Am^2 at 100 Hz was showed by the developed system. To demonstrate the feasibility of the developed system, harmonics of Nickel nanowires was measured. The harmonics generation increased with the increasing amplitude of excitation field. It can be expected that an extremely sensitive characterization of MNP is possible using the developed system.**

***Keywords*—AC susceptibility, magnetometer, magnetic nanoparticles, coil**

I. INTRODUCTION

Magnetic nanoparticles (MNPs) are widely utilized in biomedical areas such as *in-vivo* imaging, magnetic immunoassay and magnetic hyperthermia due to its characteristics of its size in nanometer scales [1]–[3]. The magnetic response of the magnetic nanoparticle can be detected by three measurement methods such as AC susceptibility [4], [5], relaxation [6]–[8] and remanence measurement [9]. The performance of the magnetic nanoparticle as a sensing target in the solution will be influenced by the magnetic properties of the magnetic nanoparticle.

There are many types of commercial magnetometers that have been used before to evaluate MNPs such as Superconducting Quantum Interference Device (SQUID) [10]–[12], vibrating-sample magnetometer (VSM) and modular Hall magnetometer [13]. However, there are disadvantages in using those three types of commercial magnetometers for evaluation of MNPs in solution. For SQUID magnetometer, the running cost is expensive due to the use of liquid Helium while commercial VSM and modular Hall magnetometer are less sensitive compared to SQUID magnetometer for evaluation of low concentration MNPs. Furthermore, the dimension of these magnetometers is significant in which they require a large space and difficult to be transported.

To achieve a compact and sensitive magnetometer for evaluation of magnetic nanoparticles in solution, an AC magnetometer consists of induction coils was developed in this work. The advantages of induction coils compared to other magnetic sensors are they are simple to fabricate, highly sensitive and having wide frequency response [14]. The developed system consists of the excitation coil and detection coil systems. The excitation coil was fabricated so that a high homogeneity and strong excitation magnetic field can be achieved over wideband frequencies. The detection coil was fabricated so that it can reach a high sensitivity and immune to environmental noises. The characteristics of the excitation and detection coil systems were measured. Harmonics responses from Nickel nanowires were measured to show the feasibility of the developed system with respect to excitation magnetic field.

II. METHODOLOGY

A. *Overall system configuration*

Fig. 1 shows a schematic diagram of the developed AC magnetometer system. The developed system consists of excitation and detection coils. The excitation coil is connected to a current amplifier (TS 250, Accel Instruments). A lock-in amplifier (LI 5640, NF Corporation) is used for the signal detection and acts as a phase-sensitive detector (PSD). Based on the reference signal from the lock-in amplifier, the current amplifier will provide a current to the excitation coil and make the coil to magnetize a sample. The current will cause the