SENSOR MATERIAL CHARACTERISATION FOR MAGNETOMETER APPLICATION

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DEDICATION

Special dedication to my beloved husband Khairul Anuar and daughter Nurin Najihah , my parents, my parent-in-laws and my families for all your love, support and care.

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ABSTRACT

AC and DC magnetic field measurements require a highly sensitive and stable magnetic sensor. In order to achieve these requirements, good properties and criteria of magnetic materials are identified. A few types of different magnetic materials have been used to study their characteristics and effect towards magnetic fields. The ring cores made from several different types of magnetic materials are designed having the same dimension so that they can be compared among each magnetic material easily. For this project, single and dual rod cores have been used as a fluxgate sensor core to observe the resulting sensor performance. Both sensors are tested with two magnetic sources; permanent magnet bar and solenoids with different diameters of wires. The output of each fluxgate sensor was processed to identify their relation with the test magnetic field density.

ABSTRAK

Pengukuran dan gangguan medan magnet arus terus dan arus ulang-alik memerlukan penderia medan magnet yang mempunyai kepekaan yang tinggi dan stabil. Untuk menghasilkan penderia tersebut, ciri-ciri bahan magnet yang baik telah dikenalpasti. Beberapa jenis bahan magnet yang berbeza telah digunakan untuk mengkaji ciri-ciri dan kesannya terhadap medan magnet. Teras gelang yang diperbuat daripada bahan-bahan magnet tersebut direkabentuk dengan dimensi yang sama bagi membolehkan perbandingan dibuat dengan mudah. Selain itu, rod tunggal dan berkembar juga telah digunakan sebagai teras penderia fluxgate, untuk melihat prestasi setiap jenis penderia tersebut. Kedua-dua penderia tersebut telah diuji dengan menggunakan dua sumber bahan magnet iaitu bar magnet tetap dan solenoid dengan diameter dawai yang berbeza. Isyarat keluaran bagi setiap penderia fluxgate seterusnya diproses bagi mengenalpasti hubungannya dengan ketumpatan medan magnet.

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LIST OF SYMBOLS AND ABBREVIATION

H	-	magnetic field intensity
B	-	magnetic flux density
G	-	Gauss
T	-	Tesla
Hz	-	Hertz
DC	-	Direct current
AC	-	Alternating current
μ	-	permeability
μ_r	-	relative permeability
χ	-	susceptibility
μ_o	-	permeability in vacuum
μi	-	initial permeability
M	-	magnetization
H_c	-	coercive force
H_{ci}	-	intrinsic coercivity
M_R	-	remanent magnetization
B_R	-	remanent or residual flux density
B_s	-	saturation flux density
μ_d	-	differential permeability
E_p	-	primary voltage
E_o	-	secondary/output voltage
N	-	number of turns
N_p	-	number of primary winding
V_{sec}	-	Induced voltage

A	-	Cross section area
D	-	Demagnetization factor
f_r	-	resonance frequency
L	-	inductance
C	-	capacitor
l	-	length of coil
D_i	-	inner diameter
D_o	-	outer diameter
R_2	-	outer radius
R_1	-	inner radius
h	-	height of ring core
w	-	width of ring core
r	-	mean radius
I_{max}	-	maximum current

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CHAPTER I

INTRODUCTION

1.1 Foreword

In this chapter, the background, purpose, objectives, and the scope of the project are discussed.

1.2 Problem Statement

Magnetic field sensing technology has been driven by the need for improved sensitivity, smaller size, and compatibility with electronic systems. Nowadays, various types and applications of magnetic sensors are produced. The techniques used to produce magnetic sensors encompass many aspects of physics and electronics.

Magnetic properties of the core such as differential permeability, coercive force, and demagnetizing factor were contributed to the sensitivity of the sensor and in producing magnetometer with better performance. This project approached various types of materials with same geometry to compare which is most suitable to be used as the core sensor, in order to produce high sensitivity magnetic field sensor and to compete with existing sensor in the marketplace.

1.3 Objectives of The Project:

This project is motivated by the following objectives:

i. To be familiar with the state of the art in magnetometer design.
ii. To identify suitable magnetic field sensor configuration for DC magnetic measurements.

1.4 Scope of Project:

The scopes of the project are as followed:

i. To implement experimental works that related to magnetic measurements.
ii. To identify the core materials properties that is most suitable for producing high sensitivity magnetic field sensors.

CHAPTER II

LITERATURE REVIEW

Magnetic field sensors play an important and continuously increasing role in many fields of science and of modern technique. Early applications of magnetic sensors were for directions finding or navigation. But today, many more uses have evolved and the technology for sensing magnetic fields has also evolved driven by the need for sensitivity improvement, smaller size, and compatibility with electronic systems.

A number of papers have been published on fluxgate magnetometer, showing different types of configurations and explaining the mechanism, importance and use of each one. The first patent on the fluxgate sensor (in 1931) was credited to H.P. Thomas. Aschenbrenner and Goubau worked on fluxgate sensors from the late 1920s; by 1936 they reported 0.3nT resolution on a ring core sensor. Since the 1980s, magnetic variation stations with fluxgates supported by a proton magnetometer have been used for observing changes in the Earth's magnetic field. Fluxgate compasses are extensively used for aircraft and vehicle navigation. Forster [1] started to use the fluxgate principle for the nondestructive testing of ferromagnetic materials. The fluxgate principle is also used in current sensors and current comparators. Compact fluxgate magnetometers are used for navigation, detection and search operations, remote measurement of dc currents and reading magnetic labels and marks.

W. Hernandez [2] has been presented a fluxgate magnetometer for high magnetic fields (<100μT). He used ferrite as the material of the core and relatively high sensitivity and linearity characteristics have been achieved, which simplified the signal processing circuit. The fluxgate magnetometer used the ring core sensor geometry, which was found to be the best for low noise sensors [3]. This is well suited for elimination of offset and instabilities of the sensor with time and temperature variations.

Fluxgate sensors serve for the measurement of DC and low frequency AC magnetic field in the range of approximately 1nT to 1mT with possible resolution of 50pT. Their principle is based on modulation of the flux in the pick-up coil by changing the permeability of the ferromagnetic core by means of the AC excitation field [4]. According to [4], most of the fluxgate magnetometers work in the feedback mode to improve the sensor linearity and increase the measurement range.

Kurt Weyand and Volker Bosse [5] have developed a new fluxgate magnetometer for measuring both magnetic dc and ac fields, with frequencies up to 2 kHz. The magnetometer has been designed using a pulse-width modulator and has a resolution of 10nT. It is possible to link up ac field quantities with dc field standards in a simple way.

Fluxset sensor is a new type of magnetometer sensor, which belongs to the family of fluxgate sensors. It has been developed and capable of measuring DC and AC (up to 200 kHz frequency) low-level magnetic fields with high accuracy. This device has sensitivity better than 100pT, operates in a wide temperature range, simple and cheap. Fluxset sensor that realize by using thin permalloy films, was developed in 2 different version; the high sensitivity version operates at DC or in low frequency range (below 100Hz) and high frequency version operates at AC up to a frequency of 100kHz [6].

Magnetic properties of the core such as differential permeability, coercive force, and demagnetizing factor were contributed to the sensitivity of the sensor [7]. The most sensitive materials are ferromagnetic. It has a high relative permeability. Ferrite, a composite material with high permeability, high resistivity, high Curie temperature and low coercive force had been chosen as the core for the fluxgate sensor. This is because the high resistivity of ferrite will decrease the eddy current losses when it is driven with high frequency alternating current. According to P. Ripka [1], ring core geometry fluxgate sensors have lower signal-to-noise ratio compared with open-end geometry fluxgate sensors.

The ring core fluxgates have in general low sensitivity, but they exhibit low noise in the input field units [8]. Rod core (Vacquier or Forster type) fluxgate sensors are very sensitive to the measured fields and resistant against perpendicular fields, but they have constructional problems and disadvantages coming from the existence of the core ends.

CHAPTER III

THEORETICAL BACKGROUND

3.1 Introduction

The earliest magnetic field detectors allowed navigation over trackless oceans by sensing the Earth's magnetic poles. Magnetic field sensing has vastly expanded as industry has adapted a variety of magnetic sensors to detect the presence, strength, or direction of magnetic fields not only from the Earth, but also from permanent magnets, magnetized soft magnets, vehicle disturbances, brain wave activity, and fields generated from electrical currents. Magnetic sensors can measure these properties without physical contact and have become the eyes of many industrial and navigation control systems.

3.2 A Review of Magnetic Sensor

Magnetic sensors differ from most other detectors in that they do not directly measure the physical property of interest. Devices that monitor properties such as temperature, pressure, strain, or flow provides an output that directly reports the desired parameter, as shown in **Figure 3.1.**

Magnetic sensors, on the other hand, detect changes, or disturbances, in magnetic fields that have been created or modified, and from them derive information on properties such as direction, presence, rotation, angle, or electrical currents. The output signal of these sensors requires some signal processing for translation into the desired parameter. Although magnetic detectors are somewhat more difficult to use, they do provide accurate and reliable data, without physical contact.

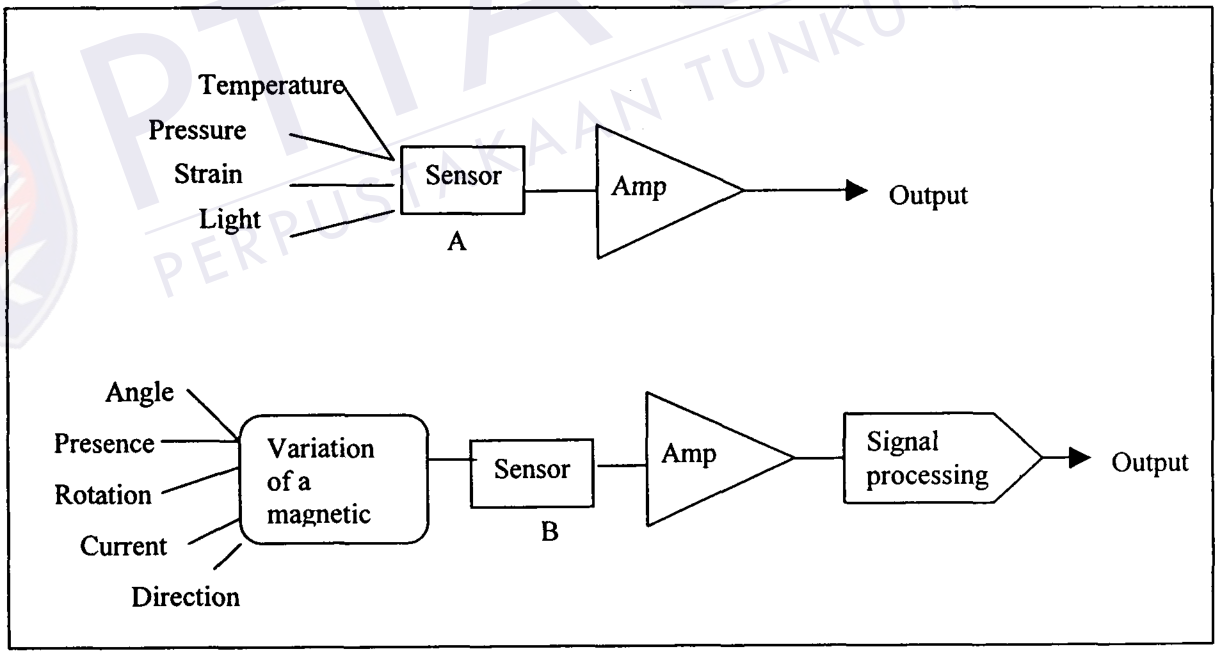

Figure 3.1: Conventional sensor versus magnetic sensing [3]

The magnetic field is a vector quantity that has both magnitude and direction. Magnet sensors measure this quantity in various ways. Some magnetometers measure total magnitude but not direction of the field (scalar sensors). Others measure the magnitude of the component of magnetization, which is along their sensitive axis (omni-directional sensors). This measurement may also include direction (bi-directional sensors). Vector magnetic sensors have 2 or 3 bi-directional sensors.

3.3 Magnetic Sensor Applications

There are a multitude of magnetic sensor applications, many of which are encountered everyday. However, the many applications can all be sorted into three basic categories. The distinction between each category is determined by how the sensor is used in relation to the ever-present Earth's magnetic field. **Table 3.1** defines the three categories and lists their major applications and most common sensors.

The boundary between categories 1 and 2 results from the magnitude of Earth's magnetic field, which varies from roughly 0.1G to 1G. For category 1, Earth's magnetic field acts as the limiting noise source. The boundary between categories 2 and 3 is the level to which Earth's magnetic field is stable.

Table 3.1: Categorization of magnetic sensor applications [3]

10^{-5} G	1 G	
Category 3 High Sensitivity	Category 2 Medium Sensitivity	Category 1 Low Sensitivity
Definition - Measuring field gradients or differences due to induced (in Earth's field) or permanent dipole moments	Definition - Measuring perturbations in the magnitudes and/or direction of Earth's field due to induced or permanent dipoles	Definition - Measuring fields stronger than Earth's magnetic field
Major Applications - Brain function mapping - Magnetic anomaly detection	Major Applications - Magnetic compass - Munitions fuzing - Mineral prospecting	Major Applications - Non-contact switching - Current measurement - Magnetic memory readout
Most Common Sensors - SQUID gradiometer - Optical pumped magnetometer	Most Common Sensors - Search coil magnetometer - Fluxgate magnetometer - Magnetoresistive magnetometer	Most Common Sensors - Search coil magnetometer - Hall-effect sensor

3.4 The Present Technology of Magnetic Sensors

Magnetic sensors have been in use for well over 2,000 years. Early applications were for direction finding, or navigation. Now, magnetic sensors are still a primary means of navigation but many more uses have evolved. The technology for sensing magnetic fields has also evolved driven by the need for improved sensitivity, smaller size, and compatibility with electronic systems. **Table 3.2** lists the various sensors technologies and illustrates the magnetic field sensing ranges.

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