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APPLICATION OF MAGNETORESISTIVE SENSORS FOR DETECTING HIDDEN FERROMAGNETIC TARGETS

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Abstract. *This paper presents a comprehensive analysis of the application of magnetoresistive sensors (AMR, GMR, and TMR) for detecting hidden ferromagnetic targets. It includes a detailed description of the types of magnetoresistive sensors, their working principles, and a comparison based on sensitivity, accuracy, noise resistance, and power consumption. The paper also explores various applications of these sensors in metal detection, highlights the current challenges, and proposes potential improvements for future research. The findings demonstrate the role of magnetoresistive sensors in ferromagnetic objects detection systems for different appliances.*

Key words: *magnetoresistive sensors, AMR, GMR, TMR, ferromagnetic objects detection*

Анатація. *У даній роботі представлено всебічний аналіз застосування магніторезистивних сенсорів (AMR, GMR та TMR) для виявлення прихованих феромагнітних об'єктів. Включено детальний опис типів магніторезистивних сенсорів, їх принципів роботи та порівняння на основі чутливості, точності, стійкості до шумів та енергоспоживання. Також досліджуються різноманітні способи застосування даних сенсорів для виявлення феромагнітних об'єктів, висвітлено поточні виклики та запропоновано потенційні вдосконалення для майбутніх досліджень. Результати демонструють роль магніторезистивних датчиків у системах виявлення феромагнітних об'єктів для різних застосувань.*

Key words: *магніторезистивні сенсори, AMR, GMR, TMR, виявлення феромагнітних об'єктів*

Introduction.

Magnetoresistive sensors are highly effective tools for detecting magnetic anomalies, which can help locate hidden ferromagnetic objects. The presence of ferromagnetic objects causes a measurable change in the electrical resistance of these sensors. By employing proper signal processing techniques, it is possible to generate images that accurately depict the location of such objects. Silicon-based magnetoresistive sensors are particularly advantageous due to their low cost, typically only a few cents per unit, making them one of the most cost-effective solutions for such detection systems [1]. Additionally, these sensors are small, lightweight, and energy-efficient, making them ideal for a wide range of applications, from security systems and industrial monitoring to archaeological surveys and geological explorations. The ability to detect slight magnetic anomalies with high precision further enhances their utility in various fields, ensuring safety and efficiency.

Main text

When using magnetoresistive sensors to detect hidden ferromagnetic objects, the hidden object can be considered a dipole within the Earth's magnetic field. This approach relies on the concept that the ferromagnetic object, such as a piece of iron, can become magnetized when placed in the Earth's magnetic field, creating a magnetic dipole moment (1).

$$B(M,R) = \frac{\mu_0}{4\pi}\left[\frac{3(M\cdot R)R}{|R|^5} - \frac{M}{|R|^3}\right] \quad (1)$$

Where: μ_0 - is the permeability of free space (vacuum permeability); M - is the magnetic dipole moment of the object; $|R|$ is the position vector from the dipole to the point where the magnetic field is being measured; (M·R) - denotes the dot product of the magnetic dipole moment and the position vector; $|R|$ is the magnitude of the position vector R [2].

The position of the hidden object relative to the sensor can be described as a function of time. The position vector R(t) represents the distance between the sensor and the ferromagnetic object and is given by:

$$R(t) = (x + \vartheta_x t, y + \vartheta_y t, z + \vartheta_z t) \quad (2)$$

As the detector sensor moves, it measures the magnetic induction B in the Cartesian coordinate system. When the sensor is at the closest proximity approach (CPA), the components of the magnetic induction B can be expressed using the provided formula for the magnetic field of a dipole. [2]

When discussing various types of magnetoresistive sensors, we will review AMR, GMR, and TMR. These solid-state sensors, fabricated using planar microfabrication processes, provide high sensitivity within a relatively compact footprint. The compatibility of solid-state magnetic sensors with complementary metal-oxide-semiconductor (CMOS) fabrication processes makes it feasible to achieve the integration of the sensor with sensing and computing circuitry at the same time, resulting in systems on a chip. These systems are highly attractive for compact, low-power ferromagnetic metal detector applications [3].

Table 1. compares AMR, GMR, and TMR sensors based on their sensitivity, resolution, power consumption, and bandwidth.

Table 1 - AMR, GMR, and TMR sensors comparison

Sensor	Sensitivity (ppm/Oe)	Resolution (nT/√Hz)	Power (mW)	Bandwidth (kHz)
AMR	4200	50	0.4545	-
GMR	6800	150	-	100
TMR	33000	2.7	0.089	100

AMR sensors offer a balance of sensitivity and power consumption, making them suitable for general applications. GMR sensors provide higher sensitivity and bandwidth, ideal for high-resolution measurements [4][5]. TMR sensors, with the highest sensitivity and lowest power consumption, are best for applications requiring precise detection of small magnetic changes. For detecting metal objects, TMR sensors are the most effective due to their superior sensitivity and low power requirements [3].

Selecting proper sensors and signal processing methods can significantly improve detection accuracy. Additionally, multiple sensors can be integrated into arrays to enhance spatial resolution and increase the detection area, enabling more precise localization of metal objects and improving the robustness of the detection system in varying environmental conditions [6].

Summary and conclusions.

In this paper, we have considered the application of magnetoresistive sensors for detecting hidden ferromagnetic objects by treating these objects as magnetic dipoles in the Earth's magnetic field. Various types of sensors, including AMR, GMR, and TMR, were reviewed, and their capabilities were compared. TMR sensors were identified as the most effective for detecting metal objects due to their high sensitivity and low power consumption. The potential for practical applications in public security systems, such as those used by police and sapper robots, was highlighted.

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