# Spatial Detection of Ferromagnetic Wires using GMR Sensor and Based on Shape Induced Anisotropy

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**Abstract:** The purpose of this paper is to introduce a new technique for inter-wire spacing measurement in a wire array using Giant Magnetoresistive (GMR) sensor. Here, the wire array is exposed to an external AC uniform magnetic field in which by scanning the probe over it, the changes in magnetic field due to the shape induced anisotropy are measured. A lock-in amplifier measures the phase between the external magnetic field and the magnetic field component measured by GMR sensor. This phase signal changes abruptly by π each time the sensor passes a wire, and therefore, the distances between the wires are detected. The results verified the possibility and the performance of the proposed inter-wire spacing measurement using GMR sensor.

**Keywords:** Demagnetization Field, GMR Sensor, Spacing Measurement, Wire Saw.

## 1 Introduction

Multicrystalline silicon solar cells are manufactured from bread-loaf sized ingots of solar-grade silicon. These ingots are sliced by a multi-wire saw mechanism consisting of a single thin and extremely long stainless steel wire wound on constant-pitch wire grooves. The wire is wound over each groove to create a web consisting of 500-700 parallel wires. As shown in Fig. 1, silicon ingots are sliced with an area of 100×100 $mm^2$ and the latest wire saw system can achieve thickness down to 300 µm with a kerf of 200 µm utilizing a wire radius, R, of 80µm [1, 2].

Commonly, computed tomography (CT scan) using a highly collimated, low energy X-ray beam, is employed to examine the pitch of wire web and high resolution CT images for samples as large as 30 mm×100 mm are provided [1, 2]. However, the related devices are expensive and sophisticated, as they need parallel beam-formation methods [3], and also, image processing methods [4, 5].

In recent years, electromagnetic methods for eddy-current inspection have attracted increasing attention. Electromagnetic sensors, based on either Hall effect, Giant Magnetoresistance (GMR) effect [6, 7], Anisotropic Magnetoresistance (AMR) [8], or SQUID have been successfully used for the implementation of ECT. Among these, the GMR sensors offer the ease of integration with conventional semiconductor technology

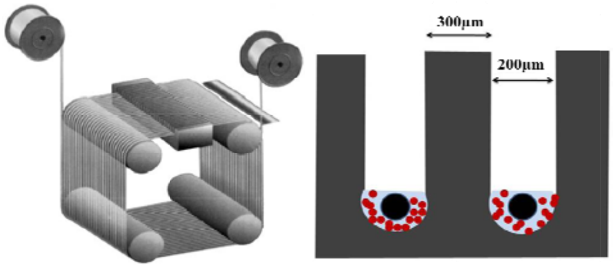


**Fig. 1** An illustration of wire saw and the wafer thickness [2].

and promises smart sensors at reasonable prices with onboard signal conditioning and input regulation [9]. They have small dimensions, high sensitivity over a broad range of frequency (from hertz to megahertz domains), low noise, operate at room temperature.

The directional property of GMR sensor can be used in a difficult problem encountered in NDE, detection of edge cracks [7], contactless angle detection [10], as well as closely spaced arrays of GMR sensors enables one-pass multi-dimensional recording [11]. Also, The ability to manufacture GMR probes having small dimensions and high sensitivity (11 mV/mT) to low magnetic fields over a broad frequency range (from dc up to 1 MHz) enhances the spatial resolution of such a probe that is applicable to Eddy Current Testing (ECT) techniques. However, in many applications eddy current measurements are adversely affected by lift-off (the distance between the probe and the test sample) variations [12].

When a ferromagnetic wire is placed in a uniform magnetic field, the magnetic field is deformed as shown

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in Fig. 2 due to the corresponding demagnetizing field. The proposed method to determine the distance between wires is to measure the x-component of magnetic flux density around the wires using a GMR sensor that scans in the direction transverse to the wire array. The proposed row spacing measurement in a wire array using GMR sensor is applicable to the Multi-wire slurry slicing.

## 2 Theoretical Derivations

Fig. 3 depicts schematically the principle of operation of the proposed method to detect the position of the wire. It is noteworthy that the direction of the external magnetic field, sensing direction and the wire axis, are perpendicular. The magnetic flux density components can be written as [13]:

$$B_r = \left( \left( \frac{\mu - \mu_0}{\mu + \mu_0} \right) \frac{a^2}{r^2} + 1 \right) B_0 \cos\theta \qquad (1)$$

$$B_\theta = \left( \left( \frac{\mu - \mu_0}{\mu + \mu_0} \right) \frac{a^2}{r^2} - 1 \right) B_0 \sin\theta \qquad (2)$$

then, the component x of the magnetic flux density along the scanning direction is derived as:

$$B_x(x) = B_r \sin\theta + B_\theta \cos\theta \qquad (3)$$

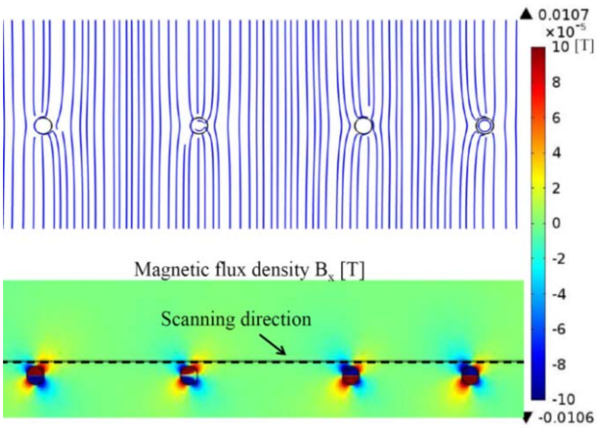


**Fig. 2** Parallel wires under an applied external magnetic field.

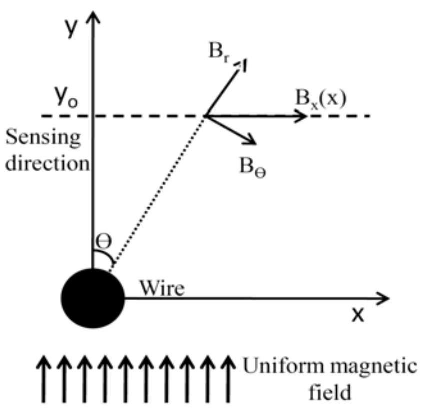


**Fig. 3** Schematic illustration of the measurement method.

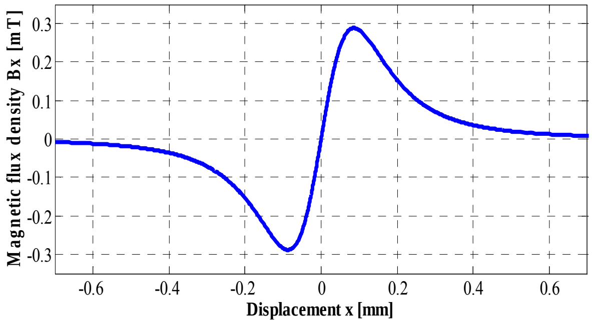


**Fig. 4** x-component of magnetic flux density versus distance.

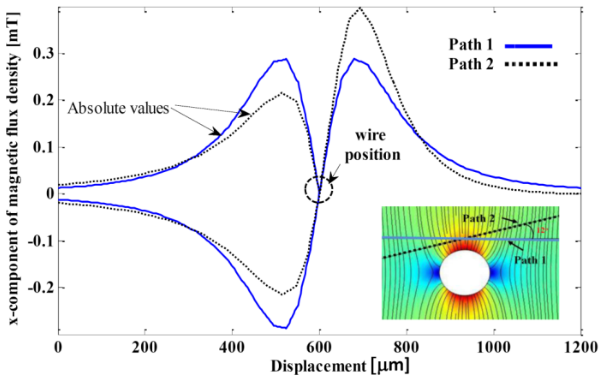


**Fig. 5** x-component of magnetic flux density along different paths.

where, $\mu_0$ and $\mu$ are the magnetic permeability of air and the wire, respectively. Putting the external magnetic flux density $B_0$=1 mT, frequency f=100 Hz the wire radius a=100 μm, the relative permeability of the wire $\mu_r$=4000 and the lift-off $y_0$=150 μm, would result in the magnetic flux density distribution depicted in Fig. 4. It is seen that the direction of $B_x$ is reversed by passing above the wire by which the location of the wire is detected.

In case of variations in the lift-off due to the vibration of the sensor, the magnetic flux density has been calculated using finite element method and Fig. 5 shows the x-component along a path with an inclination angle of 12° regarding the normal sensing direction. Again, the direction of $B_x$ is reversed by passing above the wire and shows the insensitivity of the proposed method to the lift-off variation in order to detect the location of the wire.

## 3 The Experimental Setup and the Measurements

As shown in Fig. 6, Helmholtz coil is built in order to produce uniform fields. Typical Helmholtz coil consists of two identical circular coils of 106 turns that are placed along common axis and separated by the height equal to their radius of 12.5 cm. Uniformity of magnetic field is limited to the second order. It means that it minimizes the non-uniformity in the centre of the coils.