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A GMR–ECT based embedded solution for applications on PCB inspections

Matteo Cacciola*, Giuseppe Megali, Diego Pellicanó, Francesco Carlo Morabito

University Mediterranea of Reggio Calabria, DIMET, Via Graziella Feo di Vito, 89100 Reggio Calabria, Italy

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ABSTRACT

Real-time non-destructive testing and evaluation (NDT/E) of conducting materials using eddy current techniques (ECTs) has gained significance in the last few years. This paper proposes a real-time application of ECT–NDT system exploiting giant magneto-resistive (GMR) sensors for inspection of printed circuit boards (PCBs). Probe design aims to crack inspection over flat surface, especially suitable for micro-defect detection on high density bare PCB. We propose a system based on a GMR sensor able to detect the magnetic field resulting from the interaction between a planar coil exciter and PCBs. The EC signals, detected by the GMR sensor, have been acquired by a high speed analog-to-digital (A/D) converter, for a subsequent application of signal processing based on digital techniques. The achieved results have highlighted the efficient design of the system. The advantages of the proposed models and some possible improvements of the system are also discussed.

1. Introduction

ECT is a well known method of NDT, usually applied to evaluate material flaws without changing or altering the same conducting materials. GMR sensors have recently applied to the material inspection in order to detect material cracks, based on the ECT and providing good inspection results [1–3]. ECs are induced in a specimen as a result of the application of an alternating magnetic field. For instance, a cylindrical coil could be used to produce an exciting magnetic field able to induce circular ECs constrained in an area nearby the specimen's surface. In presence of a defect, ECs' flow is perturbed: this phenomenon can be also quantified as a variation of the impedance in the exciting coil [4]. Within this framework, GMR sensors have high sensitivity over a large frequency range and a high spatial resolution because their small dimensions, thus providing a good trade-off in terms of performance versus economic cost. It has been demonstrated that the magneto-resistive probes perform better than conventional probes for low-frequency applications, i.e., when detecting deep buried flaws [5]. This is because the electromagnetic sensors are sensitive to the magnitude of the magnetic field. In the case of inductive-based probes, the output voltage is proportional to the rate of change of the magnetic field. Therefore, their sensitivity is reduced at low frequency. GMR sensors have better directional properties than other magnetic sensors because they detect the component of the magnetic field vector along their sensitive axis. The fields applied perpendicularly to the sensitive axis of a GMR sensor have negligible effect on their output. It implies that a bad position of the sensor respect to the in-study specimen's surface can cause an incorrect orientation of the sensitive axis and the probe can become insensitive to cracks. Another characteristic of GMR sensors is their self-rectifying property, making them unique among the existing transducers used in ECT. For both positive and negative applied field, the GMR sensors present always a positive output, thus behaving as omnipolar devices [1–4,6]. This aspect simplifies the signal conditioning circuit by eliminating the necessity of synchronous detection. The purpose of our work was to exploit the advantages and the benefits of GMR sensors in inspecting PCB conductors. The material basis of a PCB is a copper clad board consisting in a support having a thickness of about 1.6 mm, made of an insulating material. The most important equipment used to transfer the interconnections on the master thin layer of photosensitive material consists in an optical system applying ultraviolet light. There are two basic techniques of exposure: contact printing and proximity printing. Both may suffer of production problems, so producing defected PCBs. Within this framework, inspection of PCBs is really important since allows to characterize the defects, particularly during industrial manufacturing. In this way, it is possible to discard defected PCBs, thus saving both time and money, without assembling electronic components on flawed tracks. The inspecting system is constituted by three parts, as shown in Fig. 1: (1) the probe used for the inspection of the specimen; (2) the hardware module for the signal conditioning; (3) the software tool for signal acquisitions. Particularly, the probe is composed by a cylindrical exciting meander coil and a low field

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* Corresponding author.

E-mail addresses: matteo.cacciola@unirc.it (M. Cacciola), giuseppe.megali@unirc.it (G. Megali), diego.pellicano@unirc.it (D. Pellicanó), morabito@unirc.it (F.C. Morabito).

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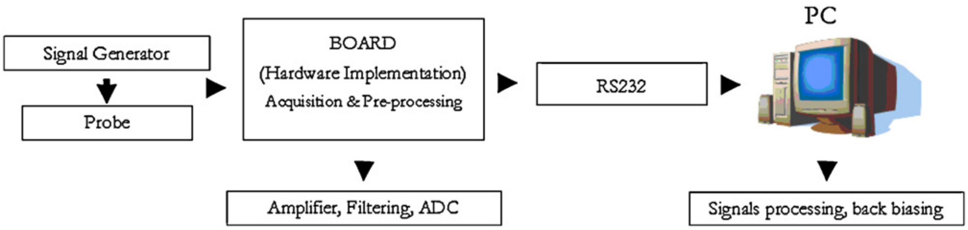

Fig. 1. Schematic representation of the presented system.

magnetic sensor for crack detection on the PCB tracks. Its design aims to crack inspection over flat surfaces, especially suitable for micro-defect detection on high density bare PCBs. Here, we propose a very simple and cheap planar coil exciter. A GMR sensor detects the magnetic field resulting from the interaction between the exciter and PCBs (GMR is located along the lower surface of the probe, and have significant advantages over traditional Hall-effect and AMR sensors [7]). The EC signals, detected by the GMR sensor, are acquired by a high speed A/D converter, for a subsequent application of signal processing based on digital techniques. This technique allows scanning of PCBs, with high sampling frequency and spatial resolution. The embedded system has been obtained with positive benefits in terms of low economic cost and high efficiency, adaptability and simplicity in realizing the proposed prototype. The paper is organized as follows. First of all, we introduce the importance of a non-destructive inspection of PCBs for detecting defect in tracks due to manufacturing faults [7]: thus, Section 2 shows the state-of-art on PCBs inspection. Subsequently, Section 3 describes the way to design a suitable coil, while Section 4 proposes the implementation of the system. Then, we present experimentations with different classes of defects in Section 5. Finally, we draw our conclusions in Section 6.

2. State-of-art about methods and devices on PCB inspection

Bare PCB inspection systems based on ECT have been developed and are successfully exploited to detect micro-defects on micro-conductors of bare PCB [8]. Moreover, ECT can be applied in inspecting the dimension and alignment of the PCB conductor [9]. The implementation of EC probe consists just on an exciting coil (or a number of exciting coils) and a magnetic sensor (or an array of magnetic sensors). Therefore, it is cost effective and very easy to manufacture. Although there are several kinds of magnetic sensors, GMR sensor is very interesting, and it is possible to use in high density PCB inspections, based on ECT [10]. Furthermore, GMR sensor can work at high frequency magnetic fields and has high spatial resolutions [11]. But, the actual scientific literature proposes low-power EC signals obtained from GMR sensors. Thus, a high performing measurement technique is required to improve signal-to-noise ratio (SNR). For the integration into PCB manufacturing process, the scanning speed and spatial resolution of inspection have to be improved for providing high inspection throughput and accurate results. In fact, integrated system of inspections could be really worthwhile for reducing the economic and commercial impacts of defected goods. Particularly, some defects may appear on PCBs, although zero-etching processes (i.e., the usage of strong acid to carve into the unprotected parts of a metal surface) are precisely prepared and controlled. Defects such as open- or short-circuits [12] have to be immediately detected in order to shelve and recover PCBs. Micro-semi cracks or filamentary shorts, poor cleanliness, or geometrical changes in the conducting paths [12] may create hidden faults, which may deteriorate the functionality of the assembled PCBs up to their uselessness. Existing methods for PCB layer inspection include various optical techniques, electrical methods, X-ray and thermal methods. One of the main requirements for all of these methods is high resolution, considering the small width of modern PCB tracks, which starts at about 100 μm.

2.1. Patents about ECT approaches for PCBs inspection

ECT is also appropriate for PCB layer testing, especially for first specimen inspection. Conventional ECTs for automated PCB testing apply electrical signals through a set of pins, and measure output signals through another set of pins. ECT systems are of two main types: “lying probes” and “bed-of-nails”. The former uses electro-mechanically controlled probes to access components on printed circuit assemblies (PCAs), and is often used for testing basic production, prototypes, and boards that present accessibility problems. The latter is typically an oblong piece of wood, the size of a bed, with nails pointing upwards out of it. It appears to the spectator that anyone lying on this “bed” would be injured by the nails, but this is not so, assuming the nails are numerous enough, since the weight is distributed between them such that the pressure applied on each nail is not enough to break the person’s skin. An exploitation of such a device is for magic tricks or physics demonstrations [13]. Both require tight mechanical contact between the pins and the tested PCB and high mechanical tolerances, as indicated for example by Soiferman in US5,424,633 [13]. A “flying probes” technique is very slow and low effective. A “bed-of-nail” system requires special and unique mechanical jigs with high mechanical precision for every PCB. Along with the recent developments in high zero-density PCBs with extremely fine parts and wiring patterns, it has become difficult to correctly place test probes onto areas to be inspected, if using an in-circuit tester. Moreover, when test probes are positioned on a high density PCB, the circuit board might be damaged due to disconnections induced in the wiring pattern, as mentioned by Kawaike et al. in US20,030,016,026 [14]. Non-contact electromagnetic systems and methods for PCB inspection are known (please refer to [15]). The main limitation of this system is its low resolution and the impossibility to reveal defects in the *Z*-direction. In other words, Soiferman’s method [15] cannot provide a high resolution three-dimensional PCB pattern image.

2.2. High and multi-frequencies for PCBs inspection

In German Patent DE19757575 [16], Daalmans describes an ElectroMagnetic (EM) microscope with an EC measuring head, where the corresponding response signal is detected inductively or capacitively via the measuring head resonance circuits. The main limitation of Daalmans’ method and system is the low inductivity of the coils, which requires the use of an excitation signal from a transmitter coil at very high frequencies. This means that the EC penetration depth is very small, and that it is impossible to detect any defects inside the subsurface region. Goulette et al. in US5,006,788 [17] describe a similar method, where a current is applied to a PCB to be inspected in order to generate an electric or magnetic field distribution on the PCB, by connecting all conducting