Printed eddy current testing sensors: toward structural health monitoring applications

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Abstract

Structural health monitoring involves periodic observations to monitor material and geometrical variations in constructions and structures. For reliable measurements, instrumentation must be set in perfect reproducible conditions. Printing sensors directly on the part to be controlled is the solution promoted in this study. This method solves the reproducibility issue, limits the Human factor influence, and leads to sensors that can be used in confined or hazardous environments.

This work was intentionally limited to eddy current testing sensors. Still, the printed-developed techniques and the conclusions are transposable to other non-destructive testing methods (ultrasounds, electromagnetic acoustic transducer, etc.). A first series of tests was conducted to establish the best dielectric and conductive ink combinations. Then, the dispenser and screen-printing methods were tested to print flat spiral coils on a flexible substrate. The resulting sensors' responses were compared to those of flex-printed circuit boards (i.e. PCB flex) of similar shapes but using copper for the electrical circuit. The new sensors were revealed to be as sensitive as the copper ones and valid for the last stage, which consisted of printing sensors on solid parts. For this, 20 turns spiral coils were printed on 3 mm thick stainless-steel plates and gave coherent electromagnetic answers, demonstrating the printed solution's feasibility.

1 Introduction

Non-destructive Testing (NDT) methods and equipment are generally in the form of measurement sensors intended to be used manually by on-site operators. Some structures requiring periodic checks are, by their environment, complicated to control. The leading causes of these difficulties can be:

- A confined environment, where operators can hardly reach the parts to be controlled resulting in shutdowns for maintenance that are potentially lengthy and expensive.
- Work at a height like civil engineering structures, where access is demanding and requires specialized operators and equipment.
- Dangerous environments being characterized by high temperatures, pressures, or radiation.

A respond to these difficulties is the SHM using miniaturized Eddy current testing, ECT architecture is simple enough to be considered for miniaturization and development in the frame of a Structural Health Monitoring (SHM) design [1]-[2]. More specifically for the sensor coil, this miniaturization is possible using planar coils made on flex Printed Circuit Boards (PCB) or even printed, through conductive inks, directly on the parts to be controlled.

2 Design rules

In SHM with permanently printed sensors it is necessary to fully pave the part's surface to be controlled (Fig. 1). Then comes the legitimate question of the pavement resolution. Ideally, it should be as fine as possible to maximize the detection efficiency. However, in the spirit of limiting costs for a large-scale industrial developments, we refused to use techniques picked up in the framework of microelectronics. We have tested different compromise in design possibly manufactured by printing such as resolution of the pavement, number of coil's turns, width of the tracs to determine the compromise to be made in order to maximize the impedance and minimize the resistance of the coil to maximize the quality factor Q (Eq.1) and reach better performance [3].

$$Q = \frac{z'}{z''} \quad (1)$$

3 Sensors developments

Three manufacturing techniques were tested for the development of the printed coils: dispenser printing, screen printing, and flex PCB. Dispenser and screen printing involves dielectric and conductive inks and allows the manufacture of the sensor directly on the part to be tested. Since ECT requires the materials to be controlled to be conductive, it is impossible to print right on a part, and a layer of dielectric insulation has to be implemented in the first stage. Then comes the conductive ink flat spiral coil layer, followed by a dielectric layer to protect the sensor from the external environment. Finally, a last conductive ink layer is required to connect the center of the spiral coil and enable electrical measurements.

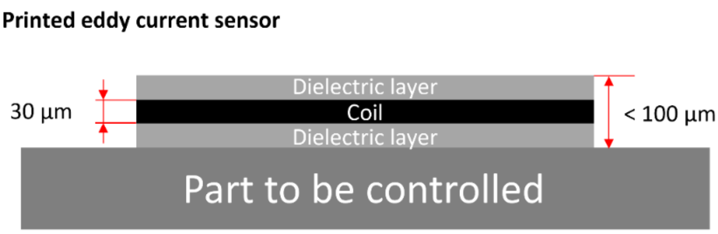

Figure 1 : Printed eddy current sensor: typical thicknesses.

4 Sensors Characterization

The sensors characterization involves placing the tested sensors far from conductive or magnetic parts and avoiding eddy current generation and/or undesired interaction and measure the electrical impedance to calculate the coil resistance, coil inductance, and quality factor. The tested frequency f was increased from 10 kHz to 5 MHz. Same tests were made but placing the sensors near a conductive and possibly magnetic specimen of different nature : stainless steel 304L, 316L, 321; steel A37, 35NCD16, 40MCD8. A clear distinction can be observed according to the nature of the tested part, especially below 2.5 MHz, confirming the viability of the sensor. They were also tested above defected part with a CF dedicated electronic showing good detection of the defects.

References

[1] Gasparin E, Santi G, Nussbaumer A. Eddy current crack monitoring system for structural health monitoring (SHM) applications. InProceedings of the 68th International Institute for Welding (IIW) Annual Assembly and International Conference, Helsinki, Finland 2018 Jun 28 (pp. 1084-1090).

[2] Nagayama T, Spencer Jr BF. Structural health monitoring using smart sensors. Newmark Structural Engineering Laboratory Report Series 001. 2007.

[3] Chen X, Ding T. Flexible eddy current sensor array for proximity sensing. Sensors and Actuators A: Physical. 2007 Mar 30;135(1):126-30