Contactless Eddy Current Sensing for Carbon Fiber Reinforced Polymer Defect Detection

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Abstract

Carbon fiber reinforced polymer (CFRP) is a high performance material that is both mechanically strong and light weight. It has seen wide applications in aerospace and civil engineering, and is being used in high-end consumer products. The composite material is composed of a polymer resin reinforced by carbon fibers. One drawback of CFRP is its susceptibility to impact damages, which raises the need for structural health monitoring. The problem has been a subject of active research recently, with many techniques proposed, including resistance method, electric potential sensing, digital image correlation, and thermal imaging [1]. Compared with these methods, eddy current sensing has advantages in contactless, reliable, and low cost [2]. The challenge in applying it to CFRP lies in the unique electric property: the conductivity is anisotropic, with higher value in the fiber direction (on order of 104 S/m, much smaller than noble metals), and much lower value in other directions (on order of 100 S/m). Therefore, the feasibility of eddy current sensing has to be investigated for CFRP defect detection

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***Abstract*—We propose a contactless defect detection method for carbon fiber reinforced polymer (CFRP) based on eddy current sensing. A pair of wire-wound coils are utilized for differential sensing with improved sensitivity for small fiber rupture defect detection. We show the effectiveness of the sensor for both surface and internal defects with numerical results.**

***Index Terms*—CFRP, eddy current, NDE.**

Carbon fiber reinforced polymer (CFRP) is a high performance material that is both mechanically strong and light weight. It has seen wide applications in aerospace and civil engineering, and is being used in high-end consumer products. The composite material is composed of a polymer resin reinforced by carbon fibers. One drawback of CFRP is its susceptibility to impact damages, which raises the need for structural health monitoring. The problem has been a subject of active research recently, with many techniques proposed, including resistance method, electric potential sensing, digital image correlation, and thermal imaging [1].

Compared with these methods, eddy current sensing has advantages in contactless, reliable, and low cost [2]. The challenge in applying it to CFRP lies in the unique electric property: the conductivity is anisotropic, with higher value in the fiber direction (on order of 10^4 S/m, much smaller than noble metals), and much lower value in other directions (on order of 100 S/m). Therefore, the feasibility of eddy current sensing has to be investigated for CFRP defect detection.

I. Initial Results

In this work, we propose and analyze a contactless sensor based on differential induced voltage using a pair of wire-wound coils for the detection of carbon fiber ruptures in a CFRP material. The system diagram is shown in Fig. 1. The carbon fibers are aligned in z direction, along which the coils move simultaneously for defect inspection. The sensor operates at 4 MHz with $1A$ input current. The frequency is chosen to achieve high resolution for small defects, while the CFRP is still maintaining a good conductivity.

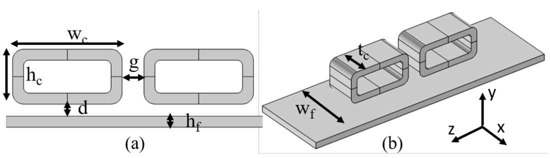

Fig. 1. Diagram of the sensing coils ($w_c = 10$, $h_c = 5$, $t_c = 5$, $g = 2$, $d = 1$, 100 turns) and the CFRP plate ($h_f = 1$, $w_f = 12.5$) in (a) side view and (b) perspective view. All units in mm.

When a coil are excited with AC current and placed close to the CFRP, eddy current will be induced in the fiber direction, which generates a magnetic field that creates an induced voltage in the coil. When a defect in CFRP occurs, the eddy current path is interrupted, causing a change in induced voltage in the coil. Fig. 2 shows the current distribution on the surface of the CFRP with fiber rupture at different positions. When there is no defect, or the detect is in the middle of the two coils (Fig. 2(a)), the differential voltage is 0; when the coils approach a defect, we expect a non-zero differential voltage, first increases, then deceases to 0 when it is aligned with the center of the coil pair, then reverses direction, and eventually becomes 0 again when the coils move away.

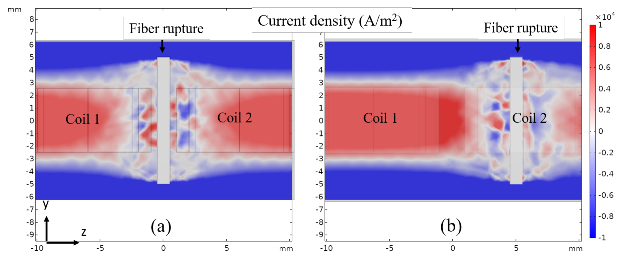

Fig. 2. Eddy current distribution with fiber rupture (a) aligned with the center of the two coils, and (b) beneath the coil on the right.

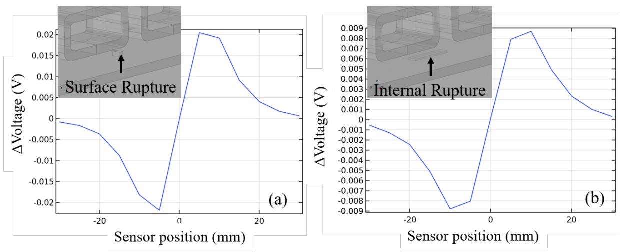

Fig. 3. Differential voltage as function of sensor position in z for a defect at $z = 0$: (a) surface rupture of size $1 \times 0.5 \times 0.5$mm and (b) internal rupture of size $1 \times 0.2 \times 5$mm and depth 0.3mm.)

Fig. 3 shows numerical results of differential voltages of the proposed design, providing two orders of magnitude higher signal as compared with a reference design using printed flat coils for the same defects [2], and making it capable of detecting very small surface and internal fiber rupture defects in the CFRP.

References

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