Fiber-Optic Sensor: A New Tool for Lightning Current Measurement

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***Abstract*— A fiber-optic current sensor is developed for measuring aircraft in-flight lightning current. It is based on Faraday Effect, which causes light polarization in a fiber to rotate when the fiber is exposed to a magnetic field. Advantages include the abilities to measure total enclosed lightning current and to conform to structure geometry. The sensor is capable of measuring 300 A – 300 KA, a 60 dB range. This paper reports test results of lighting direct and in-direct effect current amplitudes. Potential applications extend beyond aircraft and lightning uses.**

Keywords - lightning; Faraday Effect; fiber-optic; current;

I. INTRODUCTION

Sensors used in previous efforts to measure in-flight lightning current suffered from installation issues or inability to directly measure total currents. A fiber-optic current sensor was developed that addressed these concerns for in-flight measurements. When installed around structures of interest the sensor can measure the total current enclosed by the optical fiber sensing loop, much like a Rogowski coil. However, it is self-integrating, and can measure DC current. The fiber is light weight, flexible, and conformable to arbitrary structure shapes. It does not suffer from hysteresis and saturation like current transformers. Being non-conductive, the sensing fiber can be safely routed directly into the aircraft fuselage, eliminating the need for optical converters. Applications are not limited to aircraft and lightning.

II. SENSOR CONCEPT AND TEST RESULTS

Faraday Effect causes light polarization in the sensing fiber to rotate when exposed to an external magnetic field in the direction of light propagation [1,2]

$$\phi = V\int \boldsymbol{B}\cdot dl = \mu_0 V\int \boldsymbol{H}\cdot dl \qquad (1)$$

where ϕ is the polarization rotation angle in radians, V is the Verdet constant, **B** is the magnetic flux density, **H** is magnetic field, and l is length. Forming N fiber loops and applying Ampere's law result in ϕ being directly proportional to the total current enclosed I (Eq. 2). Thus, I can be determined by determining ϕ.

$$\phi = \mu_0 V\oint_N \boldsymbol{H}\cdot dl = \mu_0 VNI \qquad (2)$$

Fig. 1 illustrates a polarimetric detection scheme to determine the rotation angle ϕ. The optical scheme uses a 1310nm wideband laser, a spun highly birefringent sensing fiber [2], a reflective scheme with a Faraday mirror, and a dual-detectors setup for common-mode noise subtraction. Measurement range from 300 A to 300 kA was achieved, a 60 dB range [3].

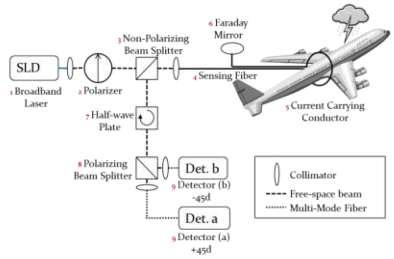

Figure 1. Optical detection scheme.

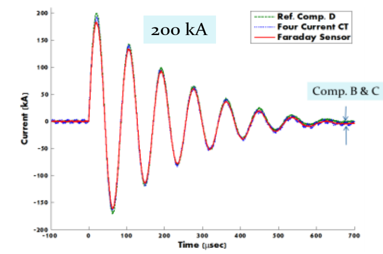

Figure 2. 200 kA current test.

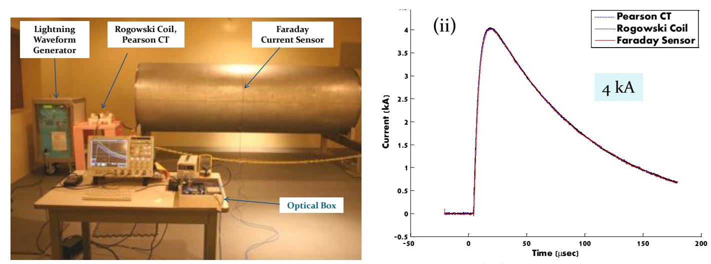

Figure 3. Measurement on a simulated aircraft fuselage.

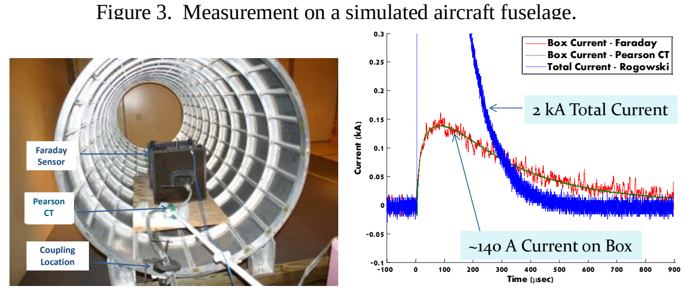

Figure 4. Low level measurement on an internal structure.

A number of tests were performed with good results. Fig. 2 illustrates a 200 kA peak current test at a commercial lightning test facility. Reasonably good results were achieved despite an imperfect setup due to installation limitations. Fig. 3 illustrates measurement on a simulated aircraft fuselage. The peak current was 4 kA, limited by the laboratory test equipment used. Fig. 4 demonstrates excellent isolation for low current measurement on an internal structure (simulating equipment or wire bundles) in the presence of a significantly larger current on the outer aluminum structure. Sensors of the same design also successfully measured triggered lightning [3] with excellent result comparisons though data are not reported here.

III. REFERENCES

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