COMMUNICATIONS

Clarification

Optical Engineering, 31(1), 34–47 (January 1992).

Advances toward fiber optic based smart structures

Author: Raymond M. Measures

In this paper, Sec. 7, "Apparent Strain and Thermal Sensitivity," was incomplete and incorrect. The correct version is printed below and is based on a more detailed paper being prepared by Valis, Hogg, and Measures.

7 Apparent Strain and Thermal Sensitivity

The change in the phase of light propagating along a structurally integrated optical fiber subject to a change in temperature, but no applied force, is another issue that has to be addressed when considering the use of optical fiber sensors for practical smart structures. This is especially true in the aerospace field, where they are likely to be subjected to considerable temperature excursions. Strain measurements made with optical fibers adhered to or embedded within such structures would thus be complicated by the appearance of *apparent strain*, due to the appreciable thermal sensitivity of the index of refraction and thermal expansion of the optical fiber and the host.

In the case of the interferometric sensors, the incremental change in the phase associated with an incremental change in both the local stress $\Delta\sigma$ and the temperature ΔT is given by:

$$\Delta\phi = \left(\frac{\partial\phi}{\partial\sigma}\right)_T \Delta\sigma + \left(\frac{\partial\phi}{\partial T}\right)_\sigma \Delta T \ . \qquad (15)$$

This can be expanded in the following form:

$$\Delta\phi = nkL\left\{\left[\left(\frac{\partial\varepsilon}{\partial\sigma}\right)_T + \frac{1}{n}\left(\frac{\partial n}{\partial\varepsilon}\right)_T\left(\frac{\partial\varepsilon}{\partial\sigma}\right)_T\right]\Delta\sigma + \left[\frac{1}{n}\left(\frac{\partial n}{\partial T}\right)_\sigma + \frac{1}{L}\left(\frac{\partial L}{\partial T}\right)_\sigma\right]\Delta T\right\} \ , \qquad (16)$$

which can be expressed in terms of Young's Modulus E and the coefficient of thermal expansion for the optical fiber α_F:

$$\Delta\phi = nkL\left\{\left[1 + \frac{1}{n}\left(\frac{\partial n}{\partial\varepsilon}\right)_T\right]\frac{\Delta\sigma}{E} + \left[\frac{1}{n}\left(\frac{\partial n}{\partial T}\right)_\sigma + \alpha_F\right]\Delta T\right\} \ , \qquad (17)$$

where the second term in Eq. (17) corresponds to the strain-optic effect and the third term in Eq. (17) accounts for the thermo-optic effect.

We can introduce the bonded fiber phase-strain coefficient,

$$g = nkL\left(1 + \frac{1}{n}\frac{\partial n}{\partial\varepsilon}\right)_T \ , \qquad (18)$$

and the free fiber thermal phase coefficient:

$$f = nkL\left(\frac{1}{n}\frac{\partial n}{\partial T} + \alpha_F\right)_\sigma \ . \qquad (19)$$

In the case of an optical fiber bonded to a host material, under conditions of no applied load other than the incremental stress arising from the difference in the coefficient of thermal expansion between the host material and the optical fiber, we can write

$$\Delta\sigma = E(\alpha_H - \alpha_F)\Delta T \ , \qquad (20)$$

where α_H is the coefficient of thermal expansion for the host material. Under these circumstances, the incremental change in the phase associated with an increase of temperature ΔT can be expressed in the following form:

$$\Delta\phi = g(\alpha_H - \alpha_F)\Delta T + f\Delta T \ . \qquad (21)$$

If we rewrite Eq. (21) in terms of an apparent strain, ε_{app}, then we have

$$\Delta\phi = g\varepsilon_{app} \ , \qquad (22)$$

and we see that the apparent strain is given by

$$\varepsilon_{app} = \left(\frac{f}{g} + \alpha_H - \alpha_F\right)\Delta T \ . \qquad (23)$$

The apparent strain sensitivity can thus be defined by the following relation:

$$\kappa = \frac{f}{g} + \alpha_H - \alpha_F \ . \qquad (24)$$

Some researchers have suggested that this problem could be overcome by simply measuring the temperature at the same time the strain is monitored. This may not be true for sensors embedded within composite materials because their anisotropic properties cause the apparent strain to depend quite strongly on the orientation of the optical fiber relative to the reinforcing fibers. In addition, the relative importance of transverse strain coupling has not yet been ascertained. Conventional resistive foil strain gauges expected to work over appreciable temperature ranges have to be tailored to the material to which they are adhered. A similar procedure may be required for fiber optic strain sensors, and this would necessitate the development of special thermally compensated optical fibers. Another approach often employed with conventional strain gauges, and more easily implemented in the near term, is to introduce a compensating gauge that is exposed to the same temperature but not the strain.

For a double pass Fabry-Perot fiber optic sensor fabricated with communications grade optical fiber, with $\alpha_F = 0.5$ (μstrain K^{-1}),

$$g = 13.3\ (\text{deg}\ \mu\text{strain}^{-1}\ \text{cm}^{-1})\ ,$$

$$f = 55.0\ (\text{deg}\ K^{-1}\ \text{cm}^{-1})\ .$$

Consequently, the apparent strain sensitivity for such a Fabry-Perot fiber optic sensor bonded to an aluminium plate [which is $\alpha_H = 23.8$ (μstrain K^{-1})] is 27.4 (μstrain K^{-1}).

Farahi et al.[27] have also considered strain and temperature cross sensitivity terms and have shown that these terms may need to be considered for large strain or temperature excursions.

Erratum

Optical Engineering, 31(1), 121–133 (January 1992).

Hybrid optical/electronic nonlinear optical devices

Authors: Nickolas P. Vlannes, Casimer M. DeCusatis, and Pankaj K. Das

In this paper, Eq. (4) was printed incorrectly. The correct form of the equation appears below:

$$\Lambda = \frac{\lambda}{2n\cos(\alpha)} \tag{4}$$