A Study of Optical Sensor Based on Fiber Bragg Grating (FBG) Using COMSOL Multiphysics

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Introduction

Fiber optic sensors can measure a large range of physical, chemical and environmental variables such as temperature, pressure, shape, position, chemical concentration, moisture, etc. Fiber optic sensors provide measurements in applications where the conventional electrical based sensors cannot be used, due to measurement requirements such as extreme temperature, small size, high sensor count, or high electromagnetic energy or radiation environments. In this paper, we propose a study of an optical sensor based on a Fiber Bragg Grating (FBG) setup arrangement using COMSOL Multiphysics. The effect of environmental parameters on the composite material machine part is observed by the modification of the length (L) of the Fabry-Perot interferometer formed by two Bragg grating mirrors. This variation can be studied by a transmission spectroscopy measurement. The developed COMSOL Multiphysics sensor model takes into account the interaction of Fiber Bragg Grating (FBG) with composite material.

Theory

In Figure 1, the schematics of a fiber optic sensor using a Fabry-Perot interferometer (FPI) is presented. It is formed by two Bragg grating reflectors of reflectance R1 and R2 separated by a fiber optic portion of length L.

The individual Bragg grating reflectors in the FPI can be characterized by transmittances Ti and reflectance R_i, i = 1, 2, such that $R_i + T_i = 1$ The Fabry–Perot reflectance RFP and transmittance TFP are found to be

$$R_{FP} = \frac{R_1 + R_2 + 2\sqrt{R_1 R_2}\cos\phi}{1 + R_1 R_2 + 2\sqrt{R_1 R_2}\cos\phi} \qquad (1)$$

$$T_{FP} = \frac{T_1 T_2}{1 + R_1 R_2 + 2\sqrt{R_1 R_2}\cos\phi} \qquad (2)$$

RFP represents the ratio of the power reflected by the FPI, P_r, to the incident power on the FPI, P_i. TFP is the ratio of the transmitted power P_t to the incident power, P_i. represents the round-trip propagation phase shift in the interferometer, defined by:

$$\phi = \frac{4\pi n L}{\lambda} \qquad (3)$$

In Eq. (3) n is the refractive index of the region between the mirrors and λ the free space optical wavelength. It has been assumed that the light experiences a π/2 phase shift at each reflection, as appropriate for dielectric mirrors, which is added to the propagation phase shift of Eq. (3). The analysis of the schematic of a Fiber Bragg Grating sensor presented in Figure 1 leads to an elementary study of Bragg grating reflector. It consists of a short section of single-mode optical fiber in which the core refractive index is modulated periodically.

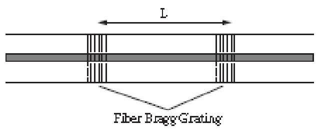

Figure 1 - Schematic of the analyzed Fiber Bragg Grating sensor.

Results and Discussion

Figure 2. Geometry of the Bragg grating fiber optic embedded composite material. The COMSOL mesh grid can be observed.

The COMSOL Metaphysics program is used to simulate the propagation of the test laser beam inside a mono mode fiber optic in order to evaluate the Fabry-Perot interferometer transmittance.

We build the geometry of the Fabry-Perot interferometer composed of two Bragg grating reflectors embedded into a piece of composite material of a common structure for aeronautical applications. In the next step we fix the boundary settings, the mesh parameters (Figures 2). The compute final solution, namely the variation of Fabry-Perot etalon transmittance with its length, for various values of Bragg grating reflectivity (Figure 3).

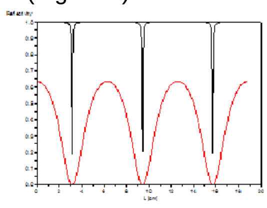

Figure 3. The simulation results obtained for the variation of Fabry-Perot etalon transmittance with its length.

Black curve - R1=0.90 and R2=0.95

Red curve - R1=0.45 and R2=0.38.

In Figure 3 the simulation results obtained in the case of Fabry-Perot etalon transmittance variation with L for several values of Bragg grating reflectivity R_1 and R_2 are presented. The Bragg grating reflectivity R_1 and R_2 were considered into two value domains, namely very high (>0.90- black curve) and very low (< 0.4 – red curve).

Conclusion

• In this paper we have demonstrated the versatility of COMSOL Multiphysics regarding the modeling and simulation of fiber optic sensor based on the use of the Fabry - Perot etalon composed of Bragg grating reflectors.

• The obtained COMSOL Multiphysics models are under development for fulfillment of aeronautic industry design needs. The considered development includes comparison with experimental results.

References

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