AN INVESTIGATION TO MEASURE MECHANICAL STRAIN IN STRUCTURES USING OPTICAL FIBER INTERFEROMETRY

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A knowledge of strain measurement is extremely important for the evaluation of civil and military structures (especially for new composite materials used in airplanes). The strain gauge is commonly used to perform such measurements. We investigate an alternative method of measuring strain using optical fiber sensors. Optical fibers have some physical and technical properties that offer some advantages over strain gauge technology.

In this investigation, a Fabry-Perot fiber optic interferometer is used to measure the strain in a vibrating aluminum beam. A data acquisition system was built using LABVIEW® to acquire and analyze, in real time, data from the interferometer. Strain measurements with the fiber optic interferometer compared favorably with a conventional strain gauge and theoretical values.

INTRODUCTION

Strain in materials and reproducible structures is measured using strain gauges. Although strain gauge technology is well understood and this method for measuring strain yields fairly accurate results, other technologies such as fiber optic sensors can offer some competetive advantages. We investigate an alternative method to measure strain using optical fibers. We believe this method when fully developed can provide a more accurate and efficient way of measuring strain. The on site measurements of strain are often transmitted to the central processing unit as electrical signals over metallic (usually copper) wires. The proposed approach transfers the strain measurement from the site to the central processing unit as optical signals using optical fibers. This approach has many distinct advantages. Optical fibers are low-cost, and are able to carry large amounts of information over long distances.

Optical fibers also have many physical properties that make them desirable. Optical fibers are generally non-corosive and light weight. Optical fibers have more appeal in areas where space, weight, and hazardous environments are issues. Because optical fibers are usually made from glass, which is a dielectric material, they are unaffected by electromagnetic interference. This is an advantage over copper in places where extra shielding might be necessary to yield accurate results.

Fiber transmitted signals may be easily multiplexed using a variety of methods. Multiplexing is already being implemented in phone lines. When applied to measuring devices such as a strain gauge, the technology of multiplexing of signals allows one to make a large number of local measurements.

BACKGROUND

The basis for the measurement of strain in the present approach is the phenomenon of interference of light waves[1]. Two light beams, obtained from a single coherent light source (a Helium-Neon laser) are brought together after having traveled different path lengths. Dark or bright fringes result depending on the difference in their path lengths. Minute changes, on the order of a wavelength of light (632.8 nm in the case of the Helium-Neon laser) can be measured in terms of the number of fringes that move past a fixed point of reference[2,3]. In other words, change in distances of about 0.6328 μm could be detected.

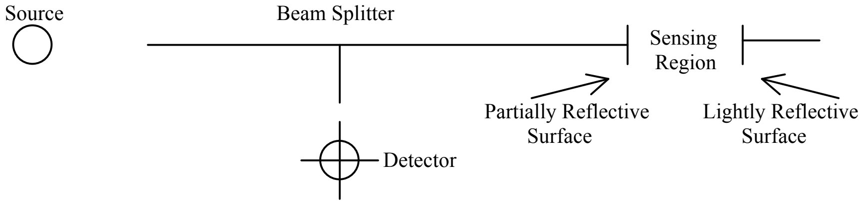

Figure 1 - Fabry-Perot Interferometer

We use the Fabry-Perot interferometer, Figure 1, in our investigation. The Fabry-Perot Interferometer has a sensing region composed of the ends of fibers with partially and lightly reflecting surfaces. A change in the environment of the sensing region such as an increase in strain, produces a change in the path length. The increase in path length causes a shift in the fringe pattern of the interfering beams. The number of fringes that shift during the changes in optical path lengths introduced by the strain is counted using a solid state photo detector. In our set up the strain in an aluminum beam is measured. A Fabry-Perot interferometer is expoxied onto the aluminum beam along side a conventional strain gauge. The bending of beam caused by stress results in a change in the path length of the interfering beams. Thus we measure the strain caused by the stress.

THEORETICAL BACKGROUND

Bending of a Mechanical Beam

We assume that the bending of the beam is uniform. Figure 2 defines the coordinate system and the relevant parameters of a uniformly bent mechanical beam. We assume small amplitude bending for the following discussion.

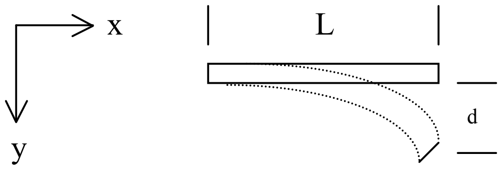

Figure 2 - Mechanical Beam

The deflection d is given by[4]:

$$d = \frac{FL^3}{3EI}, \tag{1}$$

where, F = applied force
E = Young's modulus
I = area moment of inertia about z – axis

The longitudinal strain ε_x is given by[4]:

$$\varepsilon_x = \frac{F(L-x)\left(\frac{t}{2}\right)}{EI} \tag{2}$$

Substituting (1) in this expression yields:

$$\varepsilon_x = \frac{3}{2}\frac{d(L-x)}{L^3}t, \tag{3}$$

where d is the deflection, L is the total length of the beam, x is the distance fixed end of the aluminum beam to the fiber, and t is the thickness of the beam.

Interference

The phase difference ϕ, between the two interfering laser beams is given by:

$$\phi = (2nL_g)k \tag{4}$$

$$\frac{\Delta\phi}{\phi} = \frac{\Delta L_g}{L_g}, \tag{5}$$

where n is the refractive index of the fiber, L_g is the gauge length of the fiber, and k is the wave vector of the laser light.

We assume that bending of the fiber does not introduce any significant changes in its refractive index. In addition, the temperature of the equipment and surroundings were constant throughout the experiment.

SET-UP

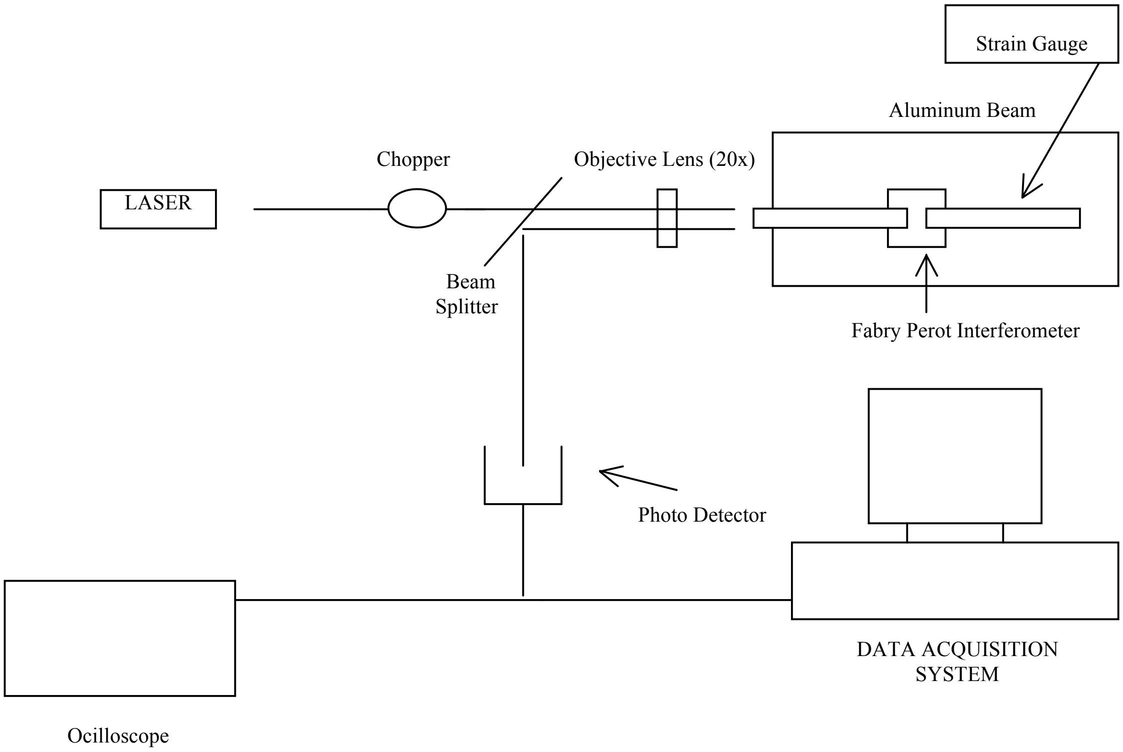

Figure 3 – Set-up used in Investigation

A Helium-Neon laser (λ = 632.8 nm) was used as the coherent light source. The beam is chopped to enhance the signal amplitude. The beam was split into two nearly equal intensity parts using a 50% reflective beam splitter. One beam, after focusing, was sent into the Fabry-Perot Interferometer, bonded by epoxy to the aluminum beam. This beam was reflected off of the partially reflective surfaces of the interferomenter and then interfered with the second beam. The resulting inteference pattern was detected by a solid state photo detector. The photo detector converted the light signal into an electrical signal. The electrical signal coming from the photo detector was monitored in real-time by the ocilloscope and data was stored by the Data Acquisition System that was built using LABVIEW®.

RESULTS AND CONCLUSIONS

The apparatus and set-up used in the present investigation is shown above in Figure 3. The data was displayed both by the ocilloscope and the LABVIEW® data acquisition system. A controlled amount of stress was put on the aluminum beam by a translation stage that was mounted just above the aluminum beam.

The photo detector which detects the maximum (bright fringes) and minimum (dark fringes), sends an electrical signal to the data acquisition system and the ocilloscope.

The values were stored and then analyzed. The value of strainwas determined for the aluminum beam. This measurement of strain was compared with the measurement reading on the strain gauge.

Table 1 - *Key Parameter Measured Values*

L	Total Length of Aluminum Beam	**464.5 mm**
L_g	Gauge Length	**2.25 mm**
t	Thickness of Aluminum Beam	**2.50 mm**
x	Distance from Fixed end of Aluminum Beam to the Fiber	**109.8 mm**
L-x	Distance inbetween fiber and point of pressure	**354.7 mm**
n	Refractive index of fiber	**1.465**

The theoretical value calculated for strain with a deflection of 6.968 mm is:

$$\varepsilon_x = \frac{3}{2} d \frac{(L-x)}{L^3} t = 92.48 \times 10^{-6} = 92.48 \mu\varepsilon$$

The experimental value calculated using equation (4) is:

$$\Delta L_g = \frac{\lambda}{2}$$

$$\frac{\Delta L_g}{L_g} = \frac{\lambda}{2nL_g} = 95.99 \mu\varepsilon$$

These preliminary results show a close agreement between theory and experiment. The small difference between the theoretical and experimental values could be caused by low precision distance measurements. We plan to improve upon the present measurement accuracy in the next phase of research.

ACKNOWLEDGEMENTS

The author wishes to express his deep appreciation to Dr. Zolili Ndlela, for his guidence and help in this investigation.

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