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BEHAVIOURAL ANALYSIS OF FIBER OPTICAL SENSOR BEAM TARGETED TO A FLAT SURFACE WITH VARIOUS TEXTURE

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ABSTRACT

The application of fiber optical sensor (FOS) in displacement measurement has advantage that contact is not required for measurement. There are applications however, in which surface reflectivity can change due to contamination and other environmental effect and therefore a closed system is required for better results for detection and measurement For example, using an optical version of a linear voltage displacement, the transformation contact of the part to be measured requires mechanical plunger, of which the FOS doesn't require physical contact. The optical sensing occurs in a closed environment in which the sensor through reflections at mirror tracks the movement of the plunger. The reflectivity has relationship to the surface has been targeted. As the surface becomes rougher, the reflected light intensity drops substantially. The sensor is also sensitive to movement of rotational as well as angularity. However, there are some difficulties with reflective optic measurement sensors. as they integrate distance data with changes in reflectivity of the target and angularity of the target. In an effort to characterize the behavior a micro finish of surface (lapped) in various coarseness, it has been observed the existing correlation between the effectiveness of the displacement due to the transformation of incident and reflective angle of the beam light.

Keywords: Fiber Optic Sensor, reflectivity, surface quality/texture, laser beam, incidence angle

1. INTRODUCTION

The Fiber Optical Sensor (FOS) beam is a light energy supplied from the light source with different wavelength. The light can then be extended to various applications depending on the desired parameter measured or controlled. The laser differs drastically from other sources, man- made, or natural in one basic way, which leads to several startling characteristics. Laser light must be coherent light. This means the light emitted by the laser is of the same wavelength and is in phase. Beam also can be transformed from the light energy to the electrical potential.

The high sensitivity of the emitted beam gives much attention during the transmission and reflection to the various targeted surface objects. For example the FOS for the displacement measurement has close correlation between the accuracy measurements of the displacement and that of surface quality to be reflected. The value of minimum accuracy can be obtained if surface is not reflective enough or the incident and the reflected light is not normal to the surface.

This has been a noted problem to in many experimental cases. Other affecting factors such as fiber microbends, fiber size type, cladding material have been noted. For some cases due to the end termination of fibers during splicing, it has also referred as loss in transmission/reflection process.

Here, for the better result, the relationship between the efficiency of the transmitting leg of the sensing to the reference leg must approaching one

The investigation through experiment is enabling to compare the effect of the surface roughness and the reflective effect due to irregularities of various surfaces. Other close factors pertaining to loss of the transmitting such as tip angular and material thickness will be also discussed.

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2. SURFACE QUALITY AND MATERIALS

According to various surface qualities, available for the materials, the acceptable characteristic of the surface such as shinning, smoothness and ability to reflect should be linked to the whole process of the beam light transmission. Materials of metal, silicate glass and foil papers are exhibiting good reflectance.

3. TRANSMISSION AND REFLECTION THEORY OF BEAM

Basic transmittance of a beam light through a glass plate for example, one the reflectance takes place at upper and lower surfaces and absorption within the plate.

The amount of incident light transmitted through the glass plate is determined by the amount of light reflected both from upper and lower surface as well as the amount absorbed within the plate

$$I = \left[(1-R)(I_o e^{-\alpha t})\right] - \left[(R)(1-R)(I_o e^{-\alpha t})\right] = (1+R)(I_o e^{-\alpha t})(1-R) = (1-R)^2 (I_o e^{-\alpha t}), \quad (1)$$

Where I_o and $I_o R$ are reflection beam and Incident beam respectively

The emitted beam from the laser source has similar principles of light transmitted through various media of materials. Reflection occurs when the light passes from one homogeneous isotropic medium to another; the light ray will bend at the interference between the two media. The expression transmission theory governed by mathematical expression of Snell's Law of

$$n_o \sin \phi_o = n_1 \sin \phi_1, \quad (2)$$

where n_o is the index of refraction of the medium in which beam light is initially traveling

n_1 is the index refraction of the second medium

ϕ_o is the angle between the incident ray and normal to the interface

ϕ_1 is the angle between the refracted ray and the normal to the interface

4. REFLECTION DUE TO THE SURFACE IRREGULARITIES WITH DEPTH T

Reflection with the lamina thickness of $\langle\langle t$ as in a) is assumed to have the $i \approx o$ since there is no internal reflection through the thickness (t). Unlike in the case (b), there is total internal reflection at a distance t to cause scattering due to angular reflections which does not give normal reflection with receiving leg o

5. SENSOR SENSITIVITY

If the reflectivity of the mirror is less than the 50% the sensor can be treated as a double pass interferometer and the value of E field can be related to the E- field launched into the optical fiber by a laser diode through the following expression.

$E_{out} = [K][T][K]E_{in}$, Where E_{in} and E_{out} are input and output fields described by the K matrix (3)

$$[K] = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & i \\ i & 1 \end{bmatrix}, \text{ and for the transudation matrix } T \text{ gives} \quad (4)$$

$$[T] = \begin{bmatrix} \exp(i\phi_s) & 0 \\ 0 & \exp(i\phi_r) \end{bmatrix}, \quad (5)$$

The above describes the phase change impressed on the light propagating down from the optic al fiber to the reflective surface and back to the detector.

ϕ_s and ϕ_r are representing the phase shift induced in the sensing and reference optical fiber, respectively. The resulting interference leads to a cosine modulation in the intensity of light arriving the detector

$$I_{out} = I_{in}\frac{1+\cos\phi}{2} \text{ where, } \phi \equiv \phi_s - \phi_r \quad (6)$$

Equipments: Displacement sensor (Philtech Model D 100 -Q), optical table ,Multimeter, oscilloscope. x-y z axis motion control.

Materials: Reflective materials of polished metal, mirror and a foil paper.

Experimental discussion: The objective of the experiment is to measure the effect of refractive incident of the beam light from the displacement FOS to various surface qualities and its response to the accuracy of displacement measurement.

After successfully calibration, some experiments were conducted to verify the effect of the incidence/reflective angle for displacement measurement. Some of the results are shown on diagram 5, 6 and 9.

The governing sensing length L is assumed to be shorter than the distance over which the strain changes appreciably

For the light that is linear polarized in the α direction the optical theory allow us to write

$$\Delta n_{\alpha} = \frac{n_{\alpha^3}}{2} P_{\alpha\gamma} \varepsilon_{\gamma} f \tag{7}$$

Where $P_{\alpha\gamma}$ is the strain-optic tensor, $\varepsilon_{\gamma} f$ is the strain tensor for optical fiber, comprising three principle and three shear strain component

$$P_{\alpha\gamma} = \begin{bmatrix} P_{11} & P_{12} & P_{12} & & & \\ P_{12} & P_{11} & P_{12} & & 0 & \\ P_{12} & P_{12} & P_{11} & & & \\ & & & P_{44} & 0 & 0 \\ & 0 & & 0 & P_{44} & 0 \\ & & & 0 & 0 & P_{44} \end{bmatrix} \text{ where, } \phi \equiv \phi_s - \phi_r \tag{8}$$

Where $P_{44} = (P_{11} - P_{12}) \frac{1}{2}$

6. REFLECTION AT THE SURFACE OF HOMOGENEOUS ISOTROPIC MEDIUM

The reflection at surface of homogeneous isotropic medium is governed by the Fresnel equation written as

$$r_s = \frac{(q_1 - q_2)}{q_1 + q_2}; r_p = -\frac{(Q_1 - Q_2)}{(Q_1 + Q_2)} \tag{9}$$

Where q_1 and q_2 are the normal components of the wave vector in the incidence medium labeled 1 for the reflecting medium and 2. r locus as function of the angle of incidence, ε dielectric constant

This reduces to

$$q_1 = \frac{w}{c}\sqrt{\varepsilon_1} \cos\theta_1 Q = \frac{q_1}{\varepsilon_1} \text{ etc} \tag{10}$$

value for the displacement as a result of variation of the angle of incidents

This can be applied for different relative dielectric constant of media in terms of refractive index as shown on table 1.

This equation (2) can be also represented by the equation for the reflection on the observation plane that varies from –90° to 90° of which is experimented to give the relationship between the beam angles to the surface of the observation plane and its corresponding distance on table 2 and on figure 6.

Table 1

No	Material	Average refractive index
1	Silica glass	1.458
2	Lapped metal	2.3
3	Foil paper	1.5

Table 2

No	Incidence angle	Observed displacement y
	0º	δ
	30	0.89 δ
	45	0.7 δ
	60	0.5 δ
	90	0
	-90	0

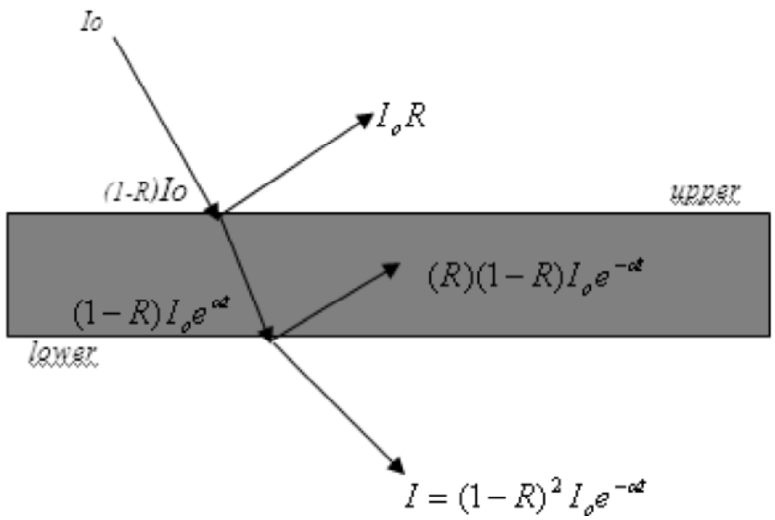

Figure 1: Basic Reflection Concept

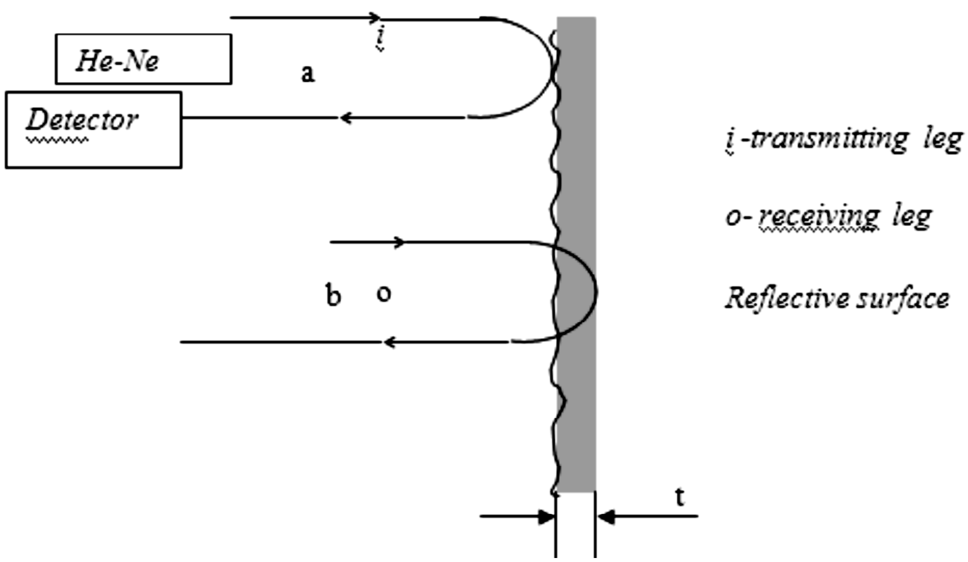

Figure 2: Reflection of Beam from FOS for Displacement Detection (a) Reflection on a Surface with a Lamina Thickness (b) Reflection through the Surface with a Thickness t of a Material

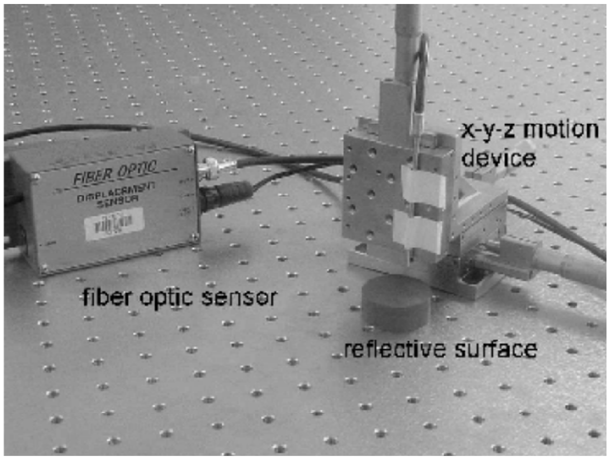

Figure 3: Experimental Setup for Reflection at an Object using FOS

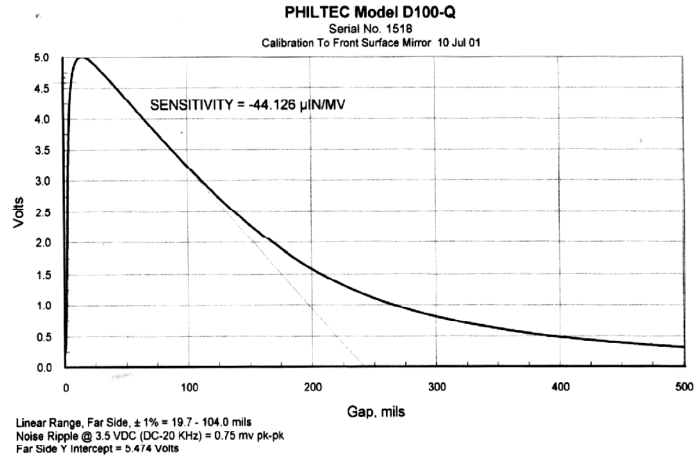

Figure 4: Philtech Standard Chart Calibrated from the Manufacturer for FOS Displacement

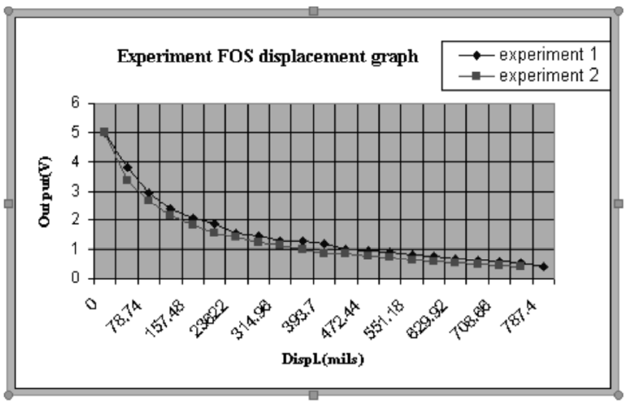

Figure 5: Displacement Graph Obtained from the Experimental Method of Calibration

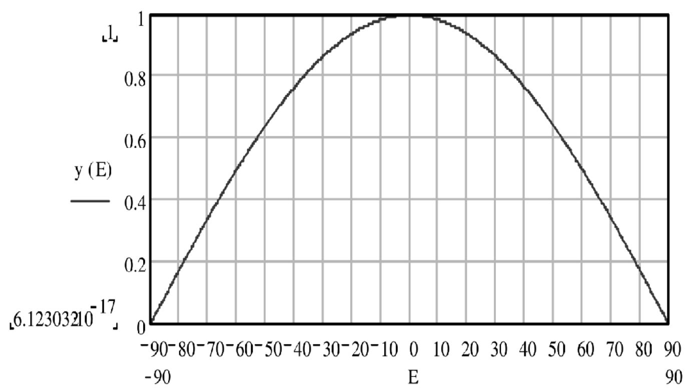

Figure 6: Relationship between *y*(*e*) and "*e*", when "δ" is a Constant

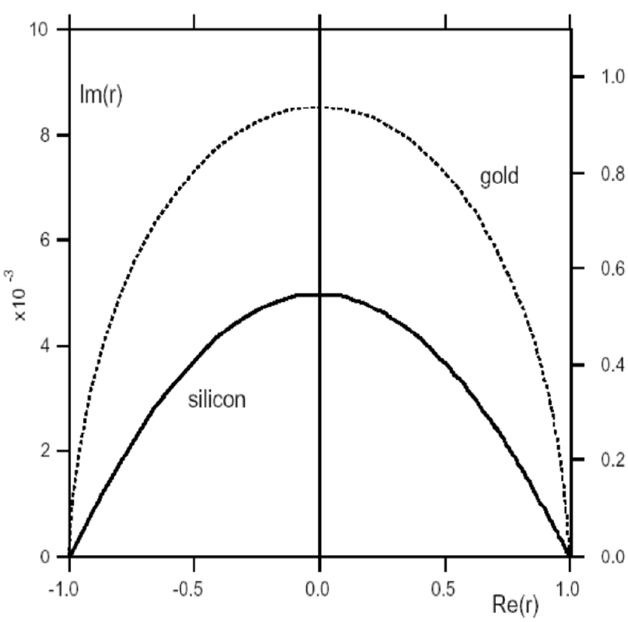

Figure 7: Displacement Relations for Two Different Material Surface

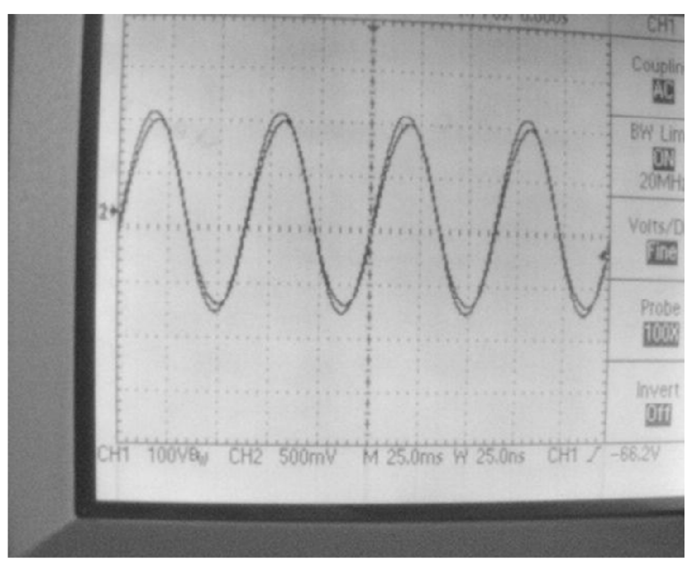

Figure 8: Result of Displacement Response Due to Multi Vibration on the Foil Material Surface

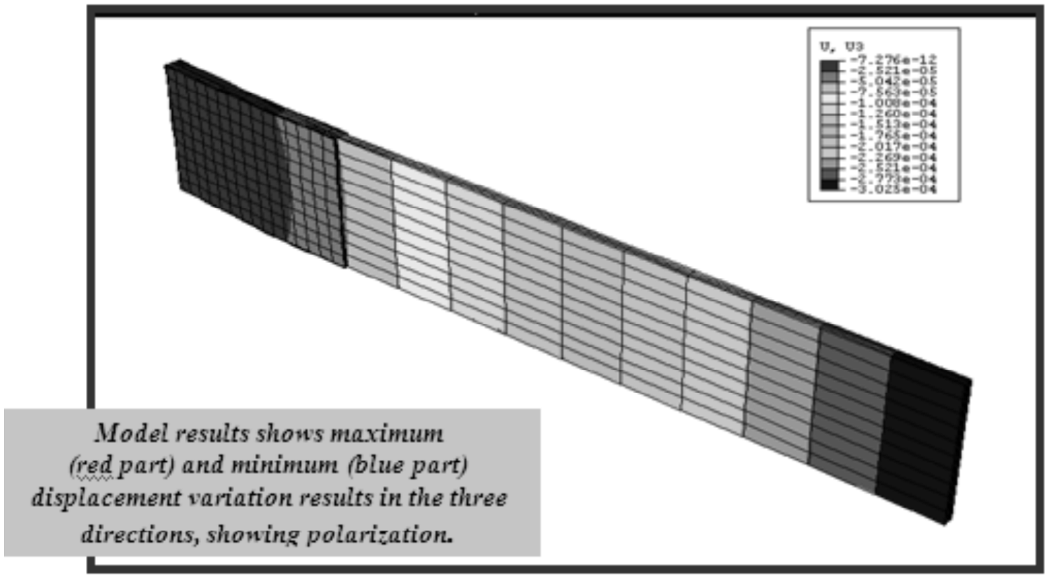

Figure 9: Simulation of Displacement using the ABAQUS

$$\delta = \frac{\lambda N}{\cos\beta + \cos\theta} \tag{11}$$

and

$$y = \frac{\lambda N}{1 + \cos\theta} \text{ or } y = \cos\theta \tag{12}$$

7. RESULT AND DISCUSSION

As discussed before the effect of the incident and reflective of the beam light targeting to the value due to the variations of surface quality as well as the angle of inclination can be obtained experimentally as well as using the Fresnel's equation to give the radius locus for determining the displacement at any give limit of angle range.

The figure 7 shows the similar result obtained by measuring the reflective effect versus the distance locus r for the surface quality of silicon and gold diagram .For this reason the figure 6 and 7 prove the correlation of accurately determining the effect to the application of the FOS for distance measurement basing on the reflectivity mechanism of the light beam. Similar tendency of results for displacement measurement was obtained after the sensor calibration of which various displacements measurement was successfully conducted.

Simulation by ABAQUS with different reflective materials across the span shows variation of displacement as shown on figure 9 above.

References

[1] David A Krohn Fiber Optic Sensor –Fundamental and Application Second Edition.

[2] Eric Udd Fiber optic smart structure.

[3] *http//www.beaglehole.com/apps/ap2reflection_theory.pdf*

[4] S. Ino ,T Tanaka and S.Okada, Jpn J.Appl.Phys(1980) L1451.

[5] William F Smith (1990), Material Science and Engineering "Refraction of Light" pp. 810.

[6] D. M. Pease, D. L. Brewe *J I Budnick Phy. Lett.* A 138, (1989), 230.