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ORIGINAL ARTICLE

Fiber Optic Based Pressure Sensor Using Comsol Multiphysics Software

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ABSTRACT
The sensing element of optical pressure sensor is used to measure the static or dynamic weight of the vehicle (i.e WIM system). In this paper reported here only the Designing and Analysis of sensing element (single mode optical fiber with steel covering) with static loads with different magnitudes. Simulation results showed that both the fiber deformation, change length of fiber and refractive index variation due to the static loads. Generally the variation of the refractive index of optical fiber due to loads (static or dynamic), the output intensity will also varied, but here I presented only the fiber deformation, refractive index variations. The study of optical fiber deformation, and to analyze the strain variations under different loads is performed using the COMSOL MULTIPHYSICS Software. Due to the strain variations we can calculate the change in length of fiber.
Keywords: single mode optical fiber, static loads, COMSOL MULTIPHYSICS Software

INTRODUCTION

A WIM system is a major tool used to collect traffic data automatically, including vehicle weight, axle load, traffic volume, classification and speed in real time. We present the design of sensing element of pressure sensor for WIM system. A pressure sensor based on the intrinsic properties of single mode optical fiber as the sensing element is introduced. The pressure sensor has the advantages of simplicity, low-cost, compactness, lead in–out in sensitivity, and capability for remote and distributed sensing [1]. This sensing element is used to measure a weight up to 15MN. To offer the required accuracy at reduced installation and maintenance costs, optic fiber-based sensors are now being developed to improve, complement or even replace the ones currently in use.

The present work describes the development of a static pressure sensor based on the intrinsic properties of optical fiber, which has simple structure, is cost effective and can potentially offer the high accuracy required for many applications. COMSOL MULTIPHYSICS Software is used to design the sensor functions. Response of the static pressure sensor are studied when subjected to static loads with different magnitudes [2]

SENSOR ELEMENT DESIGN

2.1 Theory

Single mode(SM) optical fiber is a cylindrical waveguide consists of a core and cladding with the refractive index 1.44457 and 1.4378. The basic material of glass fiber is silicon dioxide. Designing of fiber front view requires only radius of core, cladding and buffer, which are 12um,120um and 200um, but in 3D requires the length of the fiber.

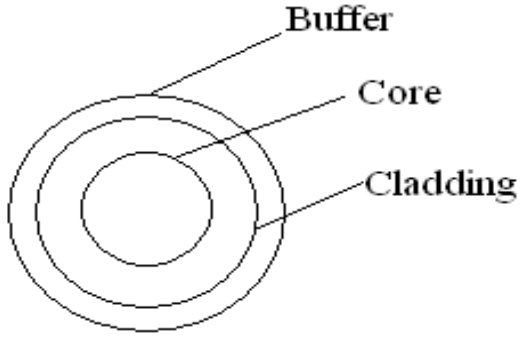


Fig No:2.1 Front view of the SM fiber(2D)

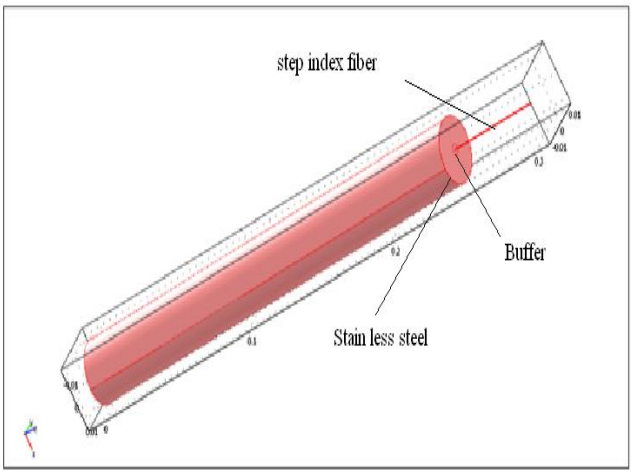


Fig No: 2.2 SM fiber with supportive materials (3D)

The core diameter of the fiber becomes smaller and smaller, the dimensions of the core start to approach the wavelength of light propagating down the fiber. As this happens, diffraction effects dominate until spatially the light is constrained to propagate only along the waveguide axis. The operating wavelength of laser source is 1550nm. The modes of light depends on the normalized frequency (V), is given by

$$V = \frac{2\pi a n}{\lambda}\sqrt{2\Delta} = 7.3403 \text{ .....1}$$

Sensor principle:

The generalized stress–optic relationship between the optical path change Δl and the strain ϵ induced over the gauge length is

$$\Delta l = l\Delta n_{eff} \text{ .....2}$$

and

$$\Delta n_{eff} = \frac{1}{2}n^2\left[(P_{11}+P_{12})(t_x+t_y) + 2P_{12}t_z\right]$$

Where *P*11 and *P*12 are the Pockels constant; *l* the length (gauge length) of the optical fiber within the pressure field; *tx, ty* and *tz* correspond to the mechanical and geometrical property of the optical fiber and the host material-epoxy. By measuring the deformation of the fiber, the strain in the host material can be measured. Using the strain ϵ expressions and stress σ in the case of plane strains (ϵ_z = 0), we obtain the refractive-index changes in the fibe

For X-polarization:

$$\Delta n_x(x,y) = -\frac{n_0^3(x,y)}{2E}\left[C_1\sigma_x + C_2\sigma_y\right] \text{.....3}$$

For Y-polarization

$$\Delta n_x(x,y) = -\frac{n_0^3(x,y)}{2E}\left[C_2\sigma_x + C_1\sigma_y\right] \text{.....4}$$

Where $n_0(x,y)$ is the refractive index of the unstressed fiber, valid for graded or step-index fibers,E is the young's modulus of the optical fiber. ϑ is the poisons coefficient of the optical fiber; σ_x and $\sigma_y$are the stress components at the point (x,y) in the fiber in the x and y directions.

$$C_1 = (1+\vartheta)[(1-\vartheta)P_{11} - \vartheta P_{12}]$$

$$C_2 = (1+\vartheta) - [(1-\vartheta)P_{12} - \vartheta P_{11}]$$

Analytical expressions of the refractive index variations at any point of the fibers can be easily calculated if we suppose that the fibers are submitted to a distribution of forces concentrated on a line along the z direction.

3. Simulation results

3.1 Electromagnetic fileds in single mode step index fiber

Fig 3.1 represents the power flow of a confinement mode in z-direction of the fiber and we can analyze the normal fields (electric and magnetic). The normal electric fields in core zone is mV/m range, but in cladding is almost negligible (10^{-16} mV/m).

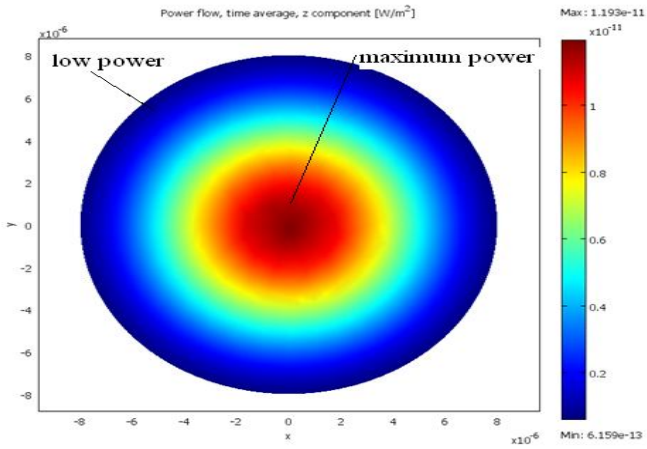


Fig No: 3.1 power flow in z-direction (2D)

In the central point maximum amount of power will be moving i.e in core Zone and cladding Zone have very less power. In 3D we can analyze the tangential fields along the length of the fiber. The below Fig 3.2 represents the tangential Electric field moving along the length of the fiber at effective refractive index 1.4457, here the length of the fiber is 2.47mm.

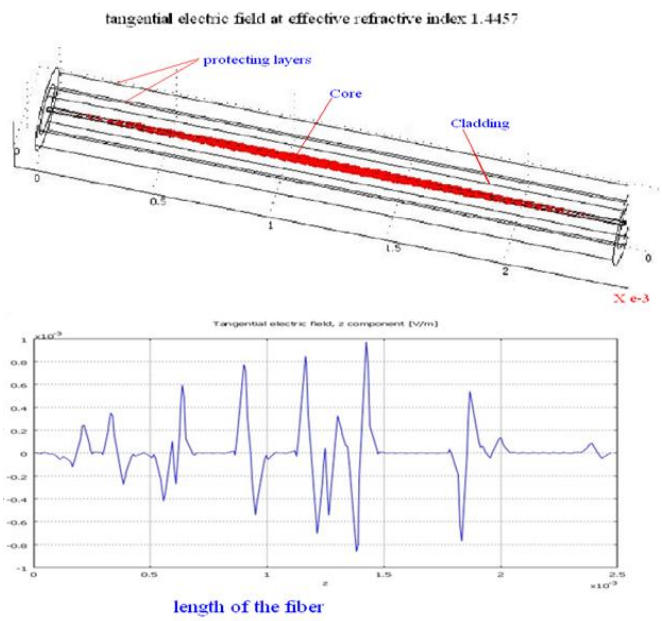


Fig No 3.2 Tangential electric field, Z- component along the length of the fiber

3.2 Stress analysis

As loading is applied to an optical fiber, the propagation constant changes due to two effects :(1) the geometry of the cross section deforms and (2) the refractive index of optical material changes due to the strain-optic effect.

Here I considered the base of the fiber will be fixed and top surface will be free and apply a static force(up to 30MN) on that, because WIM systems will placed on the road. The materials constructing the optical fiber under study in this paper are all assumed to be initially optically isotropic. The mechanical strength of the optical fiber mainly related to the young's modulus (E) and poissons ratio. For core and cladding E and poisons ratio should be 73Gpa and 0.10-0.30.

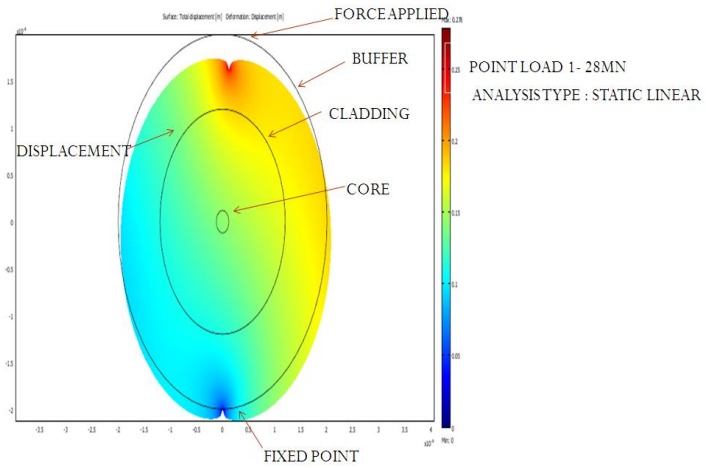
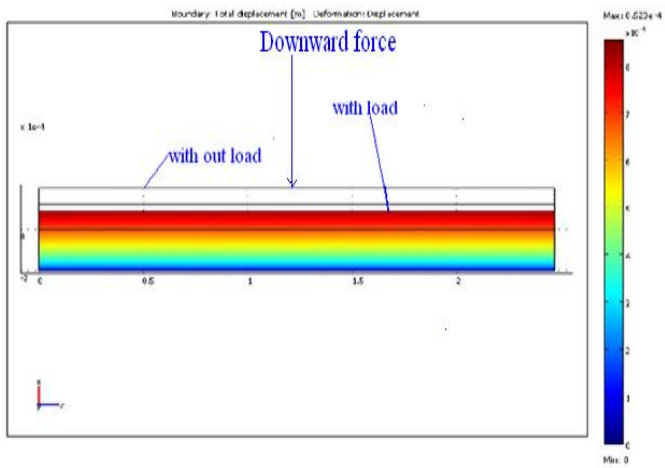


Fig No: 3.3 Force applied at top surface(2D)

Initially the fiber is in circular shape but by applying the force the shape will deform to elliptical (in 2D). This deformation has a limit, means force increases the corresponding fiber deformation also increases. But at certain force the fiber deformation decreases, because we are crossing the fiber young's modulus limit. This will gives the fiber strength and Fig 3.3 and Fig 3.4 represents the fiber deformation due to the static force with different magnitudes.



Results and discussion:

The graph 4.1 shows the deformation of the fiber by the static force. Buffer deformation is more compared to the core and cladding deformation, i.e in the order of 10^{-3}, because force is directly applied to the buffer top surface only. Due to the deformation the gauge length of the fiber will also vary.

The length of the fiber will be calculated by using strain values with equation 2 where P_{11} ,P_{12} and t_x, t_y, t_z are 0.17, 0.36. 0.0080, -0.0019, -0.0038.

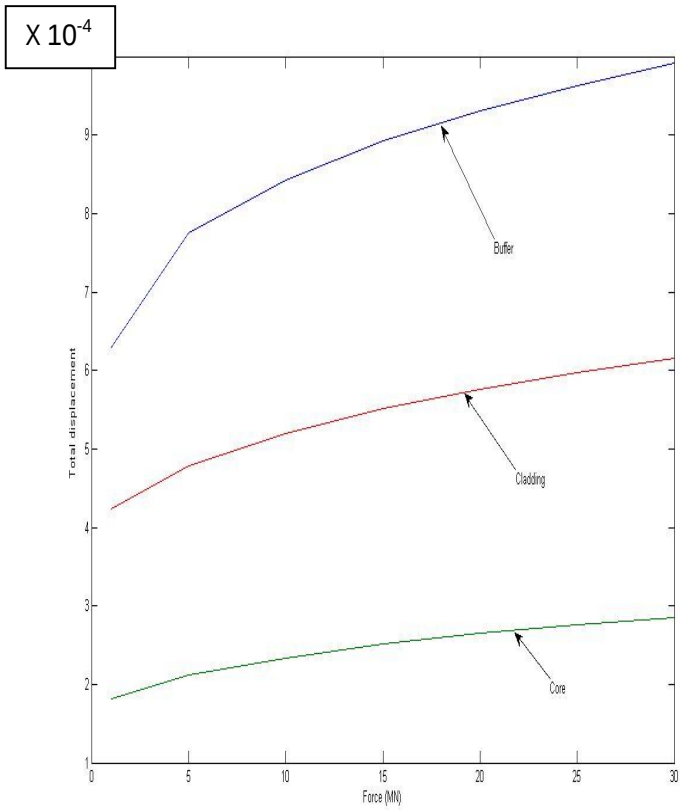


Fig No: 4.1 Force vs total displacement of the fiber

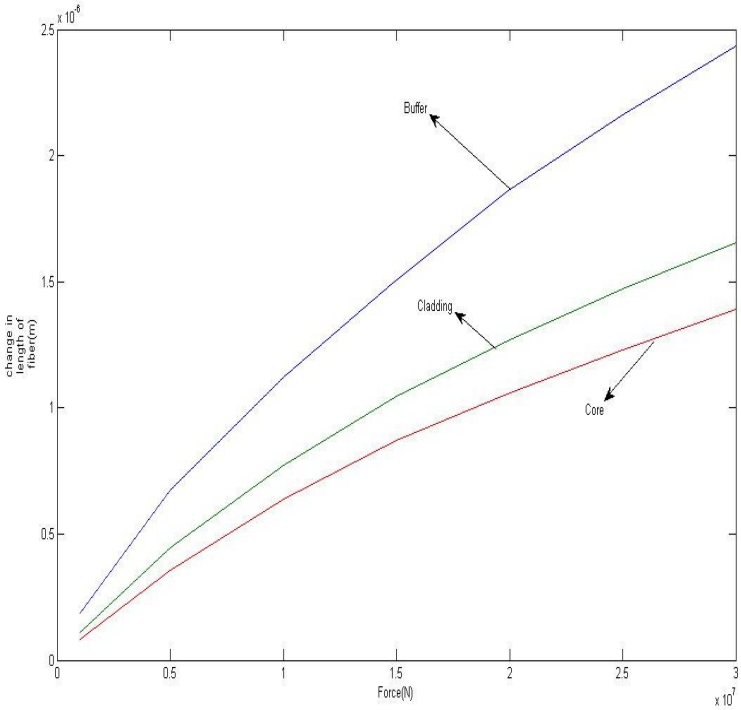


Fig No: 4.2 Force vs change in length of the fiber

The graph 4.2 shows the change in length of the fiber due to the static force. The change in length of the fiber range is in micrometers range, this is very much small, but it will affect the total internal reflection of the fiber and at that time changes the detector position (means some phase change will exist in fiber).

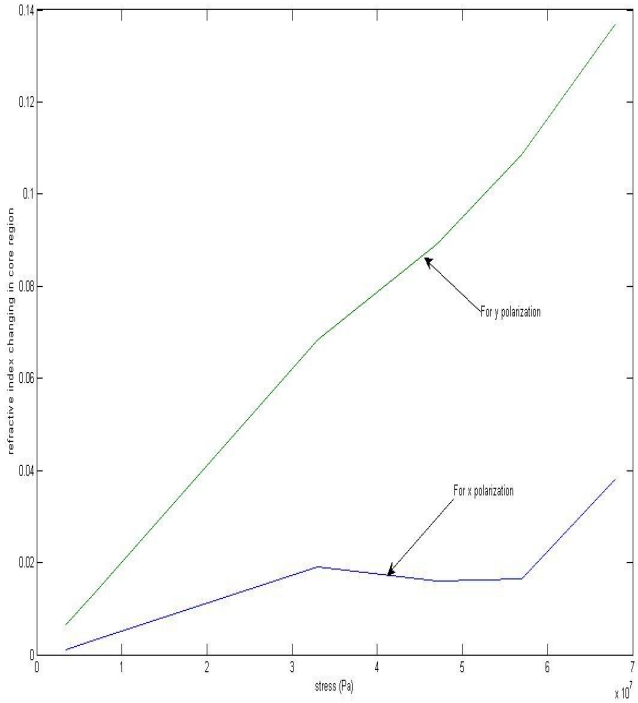


Fig No: 4.3 Stress vs Refractive index change in the core zone.

The graph shows the change in refractive index of core zone. Here to calculate the change in refractive index with young's modulus (E) and poissons ratio is 73.1eGPa and 0.17. by using these values and with the equation 3 and 4 we get x and y polarization changes. Therefore the total refractive index of the core under stress is the sum of the initial fixed one (1.4457) and change in refractive index (Fig no 4.3 values)

With this change in refractive index of the core and change in length of fiber will affect the output intensity.

CONCLUSION

The sensing element of the pressure sensor can be designed using the COMSOL MULTIPHYSICS Software. Based on deformation of fiber, we can calculate the change in length of the fiber. Similarly by using the stress σ_x and σ_y values we can calculate the refractive index changes in the core zone, with this change the output intensity will also varied. The single mode fiber with protective layers is a sensing element of the pressure sensor, which is used to measure the static weight of the vehicle or tire force. This sensing element also used to measure the dynamic weight with different loading rates, but here I mentioned only the static weight.

REFERENCES

1. Shenfang Yuana, Fahard Ansarib, Xiaohui L,iua, Yang Zhaob,(2004). Optical fiber based dynamic pressure sensor for WIM system,
2. Evaluating Weigh-In-Motion Sensing Technology for Traffic Data Collection Lixin Zhang Y. Zhao
3. F. Ansari, Intrinsic single-mode fiber-optic pressure sensor,
4. E. Udd, (1994). Fiber optic smart structure technology, in: Fiber Optical Smart Structure, 1st ed., Wiley, New York.
5. Photonic Bandgap Fibers For Transverse Strain Sensing By Patrick Stephen Van Vickle
6. R.M. Measures,. (2001). Structural Monitoring with Fiber Optic Technology, Academic Press.
7. M.C. Navarrete, E. Bernabeu, (1994). Fiber-optic weigh-in-motion sensor, Sens. Actuators A 41/42 110–113.