Microcontroller based low cost strain measurement in a single ended cantilever beam using a plastic optical fibre

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Abstract

This paper reports on the use of a Plastic optical fiber(POF) for strain sensing in a single ended cantilever experiment. The beam bending is caused by a stepper motor controller. The results show that the POF sensor exhibits good linearity in with the applied stress. The POF strain response is twice that of strain gauge response This technique has an advantage for measuring micro strain in small deflection steps of 0.4 mm/sec very precisely. Thus POF strain sensor is more useful for the measurement of strain of a structure with a low cost as well with more accuracy.

1. Introduction

Plastic optical fiber (POF) sensors have been known to be useful for measurement of several physical variables such as displacement, strain, force , stress, load, temperature, and pressure [1,2,3,4]. Hence they have found wide ranging applications in several areas such as telecommunications, structural health monitoring, biomedical applications, chemical and environmental monitoring etc. Amongst the several advantages of POFs include small dimensions, high mechanical strength, durability in harsh chemical and environmental conditions and low cost per meter.

The small dimensions of the fibre and high mechanical strength enable them to be used as embedded sensors for structural members such as composite materials[5]. They are known to provide a large elastic strain range and are more flexible than silica optical fibres. Also these are more durable in harsh chemical and environmental conditions and have high sensitivity to environmental factors. Hence they are used often for chemical and environmental monitoring. Due to their characteristics such as lightweight, non-conductivity and greater flexibility to bending they are more preferable in different fields. In addition they are insensitive to electromagnetic radiation (especially in the vicinity of power generators in construction sites) and require less expensive components. POF sensors are available at low cost and require simple solid-state devices like light-emitting diodes (LED) and photodiodes. For low-cost sensing systems, POFs are especially advantageous due to their excellent flexibility, easy manipulation, great numerical aperture, large diameter, and the fact that plastic is able to withstand smaller bend radii than glass. The advantage of using POFs is that the properties of

POFs, that have increased their popularity and competitiveness for telecommunications, are exactly those that are important for optical sensors based on optical fibers[6,7,8].

Theoretical background

The theoretical analysis of the deflections of an isotropic beam subjected to loading is well discussed [9, 10]. Fig 1 shows a cantilever beam subjected to an out of plane end-load. If L is the distance between the load and the fixed end, W= applied load, E is the Young's modulus of the beam material , M is the bending moment and I is the second moment of area of the cross section of the beam, y is the distance of the plane from the neutral axis, x is longitudinal distance from the applied load then the beam deflection δ at load end can be expressed by equation (1)

$$\delta=((-Wx^3/6) + Ax+ B)(1/EI)) \qquad (1)$$

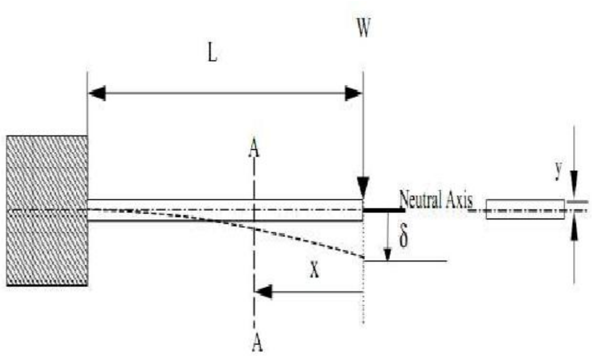


Figure 1. A cantilever beam subjected to an out-of-plane end load.

The boundary conditions for the present problem are defined by equation (2)

$$A = Wx^2/2 \text{ and } B = - (WL^3)/3 \qquad (2)$$

Substitution of the boundary conditions into equation (1) above gives deflection δ as given in equation (3)

$$\delta = ((- Wx^3/6) + (WL^2/2)x - (WL^3)/3)) (1/EI)) \qquad (3)$$

The deflection δ at the free end is given by equation (4) below by putting x=0 in equation (3)

$$\delta_{x=0} = - ((WL^3)/(3EI)) \qquad (4)$$

It can be shown that the flexural (in-plane) strain can be expressed by equation (5) in terms of the W , x, E, I as

$$\varepsilon(W,x) = -((Wx)/EI) .y \qquad (5)$$

Eliminating the load term W from equations (3) and (4) gives equation (6) which the strain at the free end

$$\varepsilon(\delta_{x=0} ,x) = ((3xy)/L^3)(\delta_{x=0}) \qquad (6)$$

Since the values of x, y and L are not varied in this study (i.e. the position of the POF sensor and distance between the fixed end and the location of the applied load was unchanged throughout the test), the flexural strain, ε, can be directly related to the deflection at the loaded end of the beam, $\delta_{x=0}$. Using equation (6) as a first approximation, it is possible to estimate the flexural strain in a beam subjected to a transverse load. In a cantilever beam configuration, it is evident that the bending moment (and by inference the curvature, 1/R) varies along the length of the beam. The response of the POF sensor therefore represents an integrated value over the length of the sensitized region (i.e. the gauge length of the sensor).

Sensors Preparation:

The surface of the POF sensor was abraded using a fresh blade causing the removal of a predetermined length of the cross section. (we refer to this as gauge sensitization length, approximate range = 2 to 3 cm.) This process of abrading increases the amount of light lost in the fibre during its bending process resulting in better accuracy. The specimens used were spring steel beams having length =300 mm, width = 30 mm and thickness = 1 mm. The plastic optical fiber was nearer to the fixed end of the cantilever beam using cyanoacrylate adhesive, and also strain gauge was pasted closer to the plastic optical fiber on the cantilever beam. This is shown in photograph at fig 4a Specified precaution were taken in mounting the strain gauges to the steel specimen.

<u>The measurement system</u>

The measurement system uses a standard multi-mode plastic optical fibre (POF) having a core diameter of 980 µm made with PMMA resin. The core is surrounded by a fluorinated polymer cladding of diameter 1000 µm. Light of wavelength (λ=630 nm) produced by a RED LED is used to inject a modulated light beam into the plastic optic fibre . The fibre is inserted into a highly sensitive phototransistor which receives the light from the source end. (refer figs 2a and 2b)

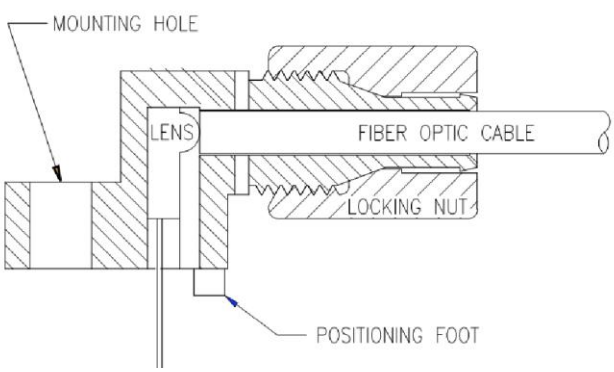


Fig 2a) The plastic optic fibre mounted in LED

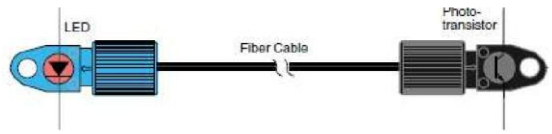


Fig 2(b) The source and receiver along with the plastic optic fibre

The output light is received by NPN phototransistor. The mounting arrangement at the source side is shown in the figure 2a. A trans-impedance amplifier was used to convert the photo transistor current in to equivalent voltage. The above voltage and the voltage from a Wheatstone bridge circuit (having two strain gauges of resistance 350 ohms each) are logged into a PC using a data acquisition card. The schematic circuit for the same is shown in Fig 3 in the next page.

Experimental Procedure:

To measure the strain of a cantilever beam the free end of the cantilever beam is deflected using a microcontroller controlled stepper motor (Model no. ESA 51E,The Electro systems associates Pvt Ltd, Bangalore, India) through a pulley arrangement. The deflection rate was set at 0.04 mm/sec The total deflection caused was 80 mm.)

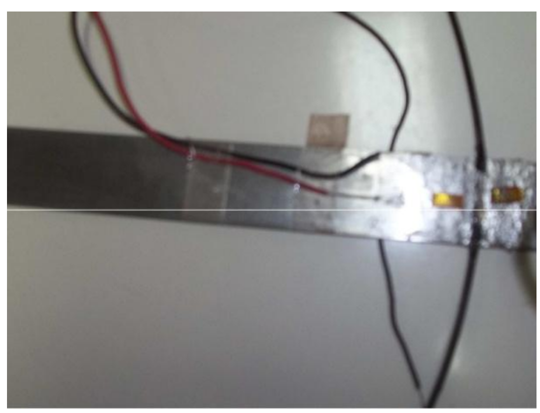
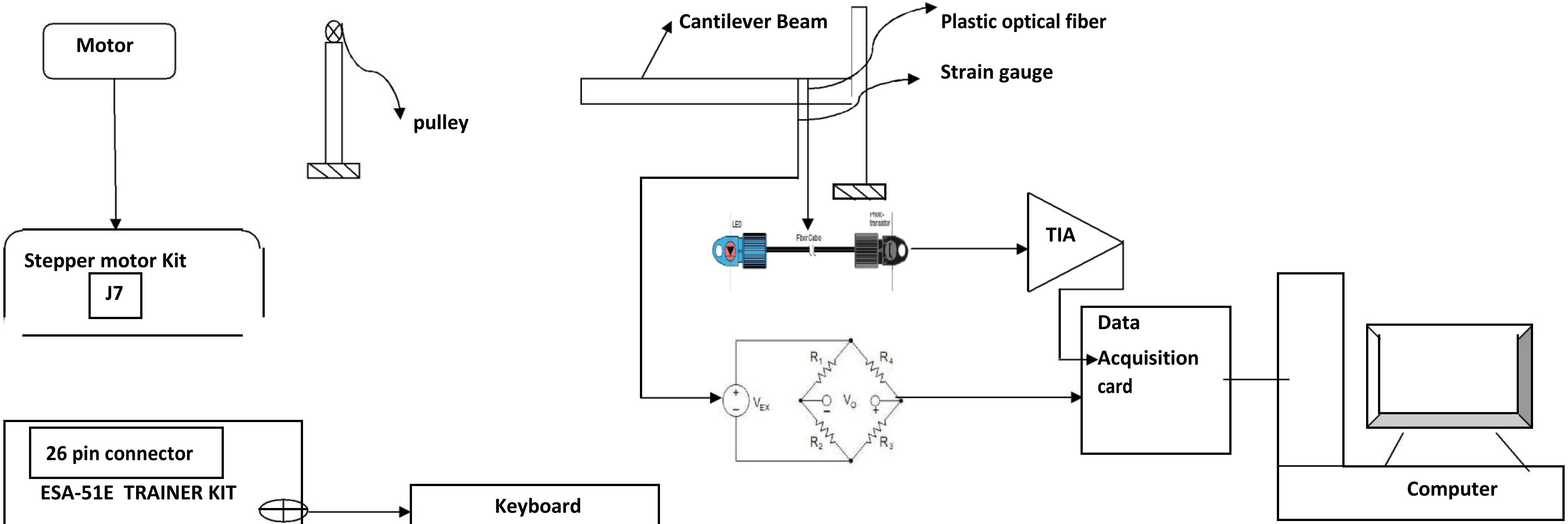


Fig 4a) Sensors (the plastic optical fibre and strain gauges) can be seen mounted on the string steel specimen.



R1, R 4 – strain gauges of 350 Ω each R2,R3-- 350Ω each

TIA-- Trans impedance amplifier

Fig 3 : Schematic circuit diagram for data acquisition

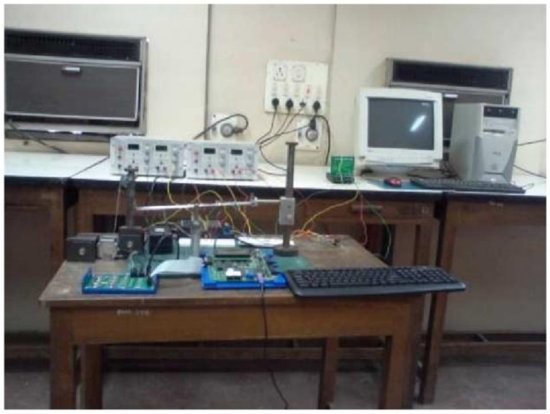


Fig 4 b) Photograph showing the experimental set up.

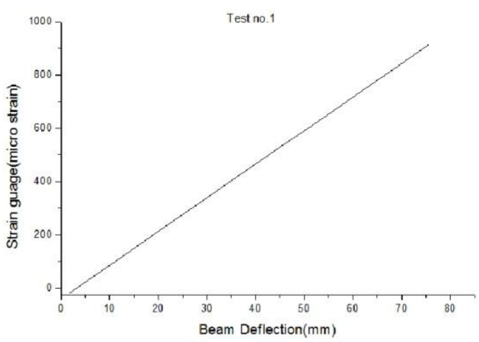


Fig 5 Graph shows between Beam deflection (mm) v/s strain measured by strain guage (microstrain (με))

Results and Discussion

Fig 5 shows a plot drawn between beam deflection(mm) v/s strain as recorded by strain gauge (hereafter (με) indicated in the rest of the text will refer to microstrain) calculated from the theoretical formula no (6) outlined in the above sections

$$\varepsilon(\delta_{x=0}, x) = ((3xy)/L^3)(\delta_{x=0})$$

Figs 6a) and 7a) shows the combined experimental plot of the data plotted between time

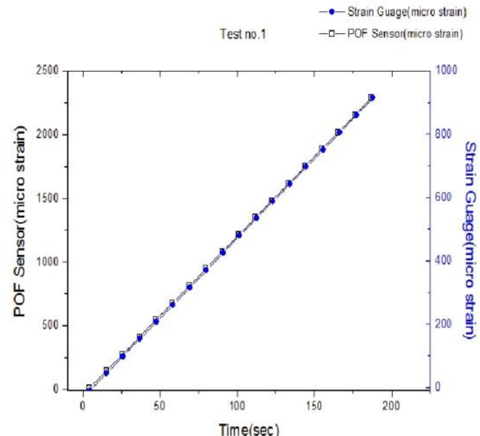


Fig 6 a)Plot between Time (s)vs Pof strain(με) vs strain guage strain (με)

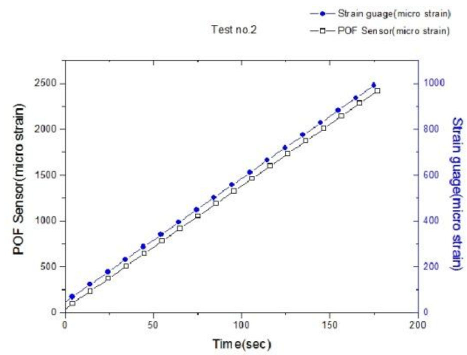


Fig 7a) Time vs POF strain(με) /strain gauge strain(με)

in sec on x-axis vs POF strain(με) and strain guage on y axis.

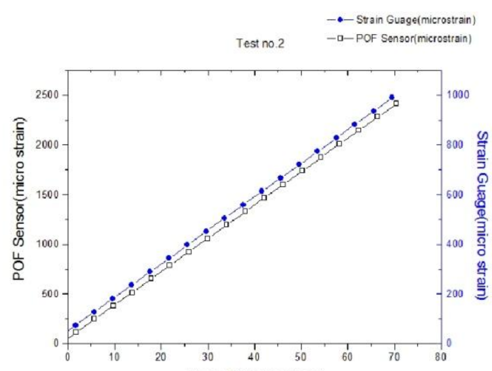


Fig 6b) Plot between beam deflection(mm) vs POF strain(με)/ strain gauge strain(με).

In Fig 6b) and 7b) a second plot is also quantities are calculated using equation 7 given below:

POF strain= calibration factor* (Raw POF signal-Initial POF Reading) (7)

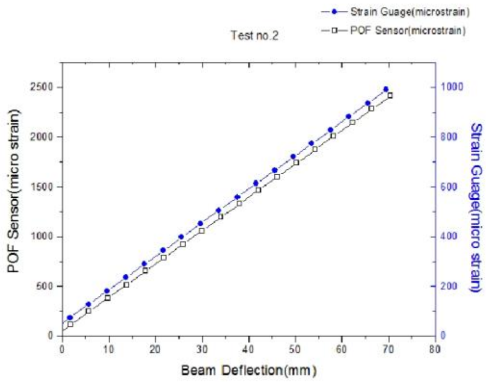


Fig 7b) Plot between beam deflection (mm) vs POF strain(με) / strain guage strain (με)

This helps us in estimation of the calibration factor given in equation (8)

Calibration factor = change in strain guage reading /change in POF intensity (8)

The strain response of the POF can be obtained from equation 7 above. It is observed that the strain response of POF is more (almost double) when compared to the strain gauge response.

Conclusions :

a) The strain measured by the POF sensor for the same beam deflection is more and almost twice that measured using strain guage circuit.

A total 15 number of tests were done for the measurement of strain using POF sensor and good agreement is observed in support of the above observation

b) The POF (plastic optical fibre) being of less cost and accompanied by other advantages we feel the method suggested here can be adopted for laboratory experiments to students of physics at graduate level

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