Sensors and Actuators A 201 (2013) 79–85

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Theoretical modeling, simulation and experimental studies of fiber optic bundle displacement sensor

Supriya S. Patil[a,*], P.B. Buchade[a], A.D. Shaligram[b]

[a] Department of Electronic Science, Abasaheb Garware College, Karve Road, Pune 411 004, Maharashtra, India
[b] Department of Electronic Science, University of Pune, Pune 411 007, Maharashtra, India

ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form 7 May 2013
Accepted 27 May 2013
Available online 1 July 2013

Keywords:
Modeling and simulation
Fiber optic bundle displacement sensor
Fiber optic sensor
Operating span
Sensitivity of fiber optic sensor
Fiber bundle configurations

ABSTRACT

This paper reports unified mathematical model of fiber optic bundle displacement sensor (FOBDS) based on ray tracing technique. The sensor response for concentric, random and hemispherical fiber bundle configurations is simulated using the developed model. The sensor performance parameters viz. sensitivity and linear operating range are calculated by differentiating the sensor response curve. It is observed that for a fiber bundle having two crowns of fibers with central illuminating fiber, sensitivity varies as 0.22, 0.42, 0.47 and linear operating range varies as 40 mm, 22 mm and 45 mm for concentric, random and hemispherical configurations respectively. These results are validated by performing experiments with the developed sensor probe. Experimental results are almost matching the simulated results. After comparing the results for three configurations, it is concluded that the hemispherical configuration is best suitable configuration for sensor showing concurrent improvement in both the sensor performance parameters.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

The performance of optical fiber bundle based micro displacement sensors has been extensively studied [1–5]. The fiber bundle arrangement is considered as a central illuminating fiber surrounded by one or more crowns of receiving fibers. Literature reports indicate that the sensitivity of the fiber bundle based sensors depends on the properties of illuminating fiber and the linear operating range is observed to be depending on the number of receiving fiber crowns in the fiber bundle [6,7]. Cao et al. proposed mathematical models for individual concentric, random, hemispherical and their hybrid combinations and validated them against experimental data [8]. In their work, different model equations are used for simulating the different configurations.

This paper describes a unified mathematical model based on ray tracing technique for the fiber bundle based sensors. The proposed model is an extension of the model reported in [9]. Three basic fiber bundle configurations for fiber optic displacement sensor (FOBDS) viz. concentric, random and hemispherical are extensively analyzed. It is revealed from the theoretical analysis that the hemispherical configuration shows best performance amongst three configurations. Experiments are carried out using a developed sensor probe for these three configurations of fiber bundles. The simulated and experimental results are compared and analyzed for validation of developed mathematical model.

2. Theoretical analysis of fiber optic bundle displacement sensor

Fig. 1(a) shows the geometry of fiber bundle consisting central illuminating fiber with two crowns of receiving fiber around it. The first crown of fibers contains 6 receiving fibers. The second crown of fibers contains 12 receiving fibers around the first crown of fibers. The circle with dark periphery shows the cross section of the cone of light reflected from the reflector at distance Z. This reflected cone of light has radius 'q'. Following the formulation of Buchade and Shaligram [4], the 'q' is given by,

$$q = a + 2Z \tan\theta \qquad (1)$$

where 'a' is the radius of illuminating as well as receiving fibers, 'Z' is the distance between the fiber end face and reflector, 'θ' is the angle of light emitting cone of the illuminating fiber and it is given by $\theta = \arcsin(NA)$, where NA is numerical aperture of the illuminating fiber.

For smaller values of Z, no overlap of the reflected cone and the receiving fiber core is observed. Hence the total received light intensity is zero. The range of Z over which this continues is called as blind region. With further increase in Z, all the receiving fibers in the first crown get partially overlapped by reflected cone of light due

* Corresponding author. Tel.: +91 9423576708; fax: +91 020 25455855.
E-mail addresses: supriya_kotasthane@yahoo.co.in (S.S. Patil), buchadepb@gmail.com (P.B. Buchade), adshaligram@gmail.com (A.D. Shaligram).

0924-4247/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.sna.2013.05.032

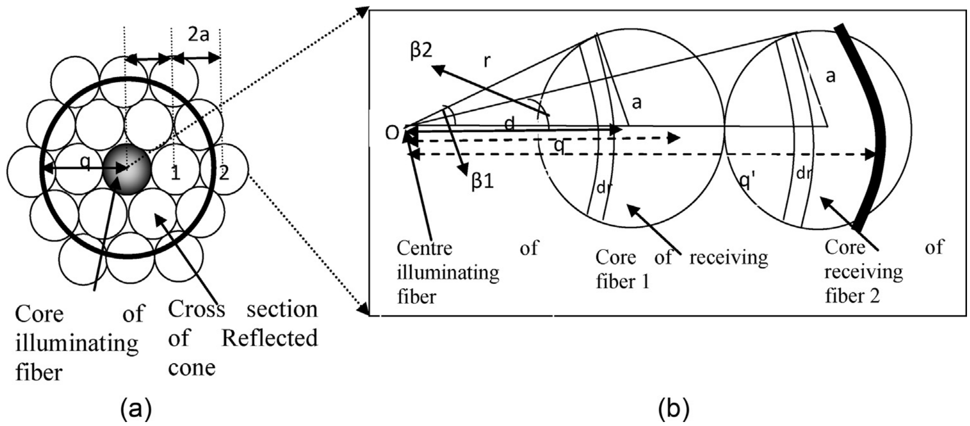

Fig. 1. (a) Overlap area and (b) calculation of received intensity by receiving fibers in consecutive crowns.

to illuminating fiber. This continues till receiving fibers in the first crown get totally overlapped by reflected cone. The total received light intensity shows linear increase with distance Z. The range of Z over which this continues is called as linear operating range.

Let 'd' (=2a) be the distance between the centers of illuminating fiber and receiving fiber in the first crown as shown in Fig. 1(a). Thus the radial spread of partial overlap condition is to be considered from $d - a$ to $d + a$. The power received in this region is calculated by dividing the overlap area into angular strips as shown in Fig. 1(b). Here 'r' is identified as the distance between the center of illuminating fiber and the angular strip 'ds'. In this way, total received power by all receiving fibers in the first crown of fibers is calculated by integrating the received power for each receiving fiber in the partial overlap region and is given by the equation

$$P_{(\text{partial\_overlap})} = \int_{q=a}^{q=3a} \frac{2I(r)\beta_1(r)r}{Z^2 + q^2(Z)} dr \quad a \le q \le 3a \tag{2}$$

Here, $2\beta_1(r)rdr$ represents the shaded area bounded by the limits in the first crown of fibers as shown in Fig. 1(b). It is given by

$$\beta_1 = arccos\left(\frac{r}{2a} - \frac{3a}{2r}\right) \tag{3}$$

$I(r)$ is power irradiated by the illuminating fiber and is given by

$$I(r) = \frac{P_E}{\pi Z^2} \tag{4}$$

P_E is power launched into the illuminating fiber by source LED or LASER.

For larger values of Z, all the receiving fibers in the first crown get totally overlapped by reflected cone of light. The received light intensity depends on the distance between the receiving fiber and the image of the illuminating fiber in the reflector and varies as inverse square law for this distance $R = \sqrt{(2Z^2 + q^2)}$. The received intensity shows non linear variation with the distance Z. Hence this region of Z is known as non linear region.

$$P_{(\text{Total\_overlap})} = \int_q \frac{I(r)dr}{(2Z)^2 + q^2} \quad q > d + a \tag{5}$$

With further increase in distance Z, the reflected cone of light overlaps the receiving fibers in the second crown of fibers as shown in Fig. 1(b). The dark circular periphery indicates the cross section of the reflected cone having radius 'q' (=4a) for larger values of Z. The total received light intensity $P_{\text{partial\_overlap}}$ by second crown of fibers is obtained similar to Eq. (2) derived for first crown and is given by

$$P_{(\text{partial\_overlap})} = \int_{q'} \frac{2I(r)\beta_2(r)r}{Z^2 + q'(Z)^2} dr \quad \text{where} \quad 3a \le q' \le 5a \tag{6}$$

and $2\beta_2 rdr$ represents the shaded area for fiber in the second crown and it given by

$$\beta_2 = arccos\left(\frac{r}{2a} - \frac{15a}{2r}\right) \tag{7}$$

Thus total received intensity by a fiber bundle having two crowns of the receiving fibers at the situation shown in Fig. 1(b) is given by the summation of Eqs. (5) and (6). For exactly circular fiber bundle, having N_{R1} receiving fibers in the first crown and N_{R2} receiving fibers in the second crown around the central illuminating fiber, total received light intensity is given by

$$P(TOTAL(tworings)) = \underbrace{N_{R1}\int_{q'} \frac{I(r)dr}{Z^2 + q'(Z)^2}}_{\substack{\text{For first crown}\\ \text{(total overlap)}}} + \underbrace{N_{R2}\int_{q'} \frac{2I(r)\,\beta 2(r)}{Z^2 + q'(Z)^2} dr}_{\substack{\text{For second crown}\\ \text{(Partial overlap)}}} \tag{8}$$

where $3a \le q' \le 5a$.

Eq. (8) is modified for the fiber bundle having 'i' crowns with $6i$ fibers in each crown with d_i as center to center distance between the illuminating fiber and the receiving fiber in the ith crown where $i = 1, 2, 3, \ldots, N$. total received light intensity is given by

$$P(TOTAL) = \underbrace{\sum_{i=1}^{N-1} 6i\int_{q'} \frac{I(r)dr}{Z^2 + q'(Z)^2}}_{\substack{\text{For (N-1) crowns}\\ \text{(total overlap)}}} + \underbrace{6N\int_{q'} \frac{2I(r)\,\beta_i(r)}{Z^2 + q'(Z)^2} dr}_{\substack{\text{For N}^{\text{th}}\text{ crown}\\ \text{(Partial overlap)}}} \tag{9}$$

where $(d_i - 1)a \le q' \le (d_i + 1)a$, where $i = 1, 2, 3, \ldots$ $d_i = 2i$ for all radial positions of the fiber. $d_i = \sqrt{(3/2)}i$ for non radial positions of the fiber. $\beta_i = \arccos((r/2a) - (((2N)^2 - 1)a/2r))$.

Download English Version:

https://daneshyari.com/en/article/7137586

Download Persian Version:

https://daneshyari.com/article/7137586

Daneshyari.com