Optics and Laser Technology 98 (2018) 339–343

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

A novel fiber bundle configuration for concurrent improvement of displacement range and sensitivity of self-referenced fiber optic displacement sensor

Shrikant Maske [a,*], P.B. Buchade [b], A.D. Shaligram [a]

[a] Department of Electronic Science, Savitribai Phule Pune University, Pune 411007, India
[b] Abasaheb Garware College, Karve Road, Pune 411004, India

ARTICLE INFO

Article history:
Received 10 April 2017
Received in revised form 17 July 2017
Accepted 14 August 2017
Available online 31 August 2017

Keywords:
Fiber optic displacement sensor
Self-reference
Linear array
Asymmetry

ABSTRACT

In this paper, efforts done towards simultaneous improvement in linear displacement range and sensitivity of self-referenced fiber optic displacement sensor (FODS) are reported. A comparative study of three different configurations of self-referenced FODS having same geometrical structure has done. All configurations contain one transmitting fiber and two receiving fiber groups. The self-referencing is effected by taking the ratio of outputs of second to first receiving group. A transmitting and a receiving fiber in a first receiving group are same. In type I configuration, the second receiving group has three optical fibers are collinear. In type II configuration, the second receiving group has an optical fiber having core diameter three times to transmitting fiber. In type III configuration, the second receiving group has seven optical fibers which are arranged in a circular fashion. In type I and III configuration, all optical fibers are identical and the output of second receiving group is taken as a sum of outputs of receiving fibers. The simulations and experimentations are carried out for all configurations. The obtained linear displacement ranges are 2.1, 1.3 and 2 mm with sensitivities of 0.42, 1.25 and 1.31 mm^{-1} having less than 2% nonlinearity error for type I, II and III configurations. Type III configuration offers improved linear displacement range and sensitivity as compared to type I and II.

1. Introduction

Intensity modulation based fiber optic displacement sensors having different configurations are reported in the literature [1]. Fiber optic displacement sensors (FODS) have been used for the determination of various parameters like vibration, stain formation on human teeth and thickness of reflector [2–5]. Self-referenced FODS is immune to change in light source intensity and reflectivity of a reflector [6]. Self-referencing is also used to improve linear displacement range and sensitivity of FODS. Several researchers [7–12] have used the Gaussian beam approach for the modelling of fiber optic displacement sensors. Yang and Oyadiji [11] have reported a self-referenced intensity modulated linear array based FODS to improve linear displacement range and sensitivity. Due to the linear arrangement of receiving fibers, the light receiving area is small. Therefore the further improvement in sensitivity is limited. Lim et al. [12] have reported a bifurcated FODS having asymmetry in core radius of transmitting and receiving fiber. It has been shown that the linear displacement range is increased with increasing the core radial ratio between receiving fiber and transmitting fiber. However, the sensitivity is reduced.

In this paper, a new approach towards simultaneous improvement in linear displacement range and sensitivity of self-referenced FODS is reported. According to Yang and Oyadiji, the linear displacement range and sensitivity is increased using configuration as shown in Fig. 1(a) (Now onwards it would be referred to as type I). In type I configuration, the second receiving group has three optical fibers which are identical to transmitting fiber. Self-referencing is effected by taking the ratio of receiving fiber outputs from group 2 and group 1. With this arrangement though the linear displacement range is significantly increased, the sensitivity increase is limited. According to Lim et al. the linear displacement range is increased with increasing the core radial ratio between receiving fiber and transmitting fiber. Fig. 1(b) shows a configuration (Type II) based on a similar concept but adding group 1 receiver for self-referencing. In type II configuration, the second receiving group has one optical fiber having core diameter three times of transmitting fiber. Self-referencing is done by taking the ratio of receiving fiber outputs from group 2 and group 1. The improvement

* Corresponding author.
E-mail address: maske.shrikantmadan@gmail.com (S. Maske).

http://dx.doi.org/10.1016/j.optlastec.2017.08.006
0030-3992/

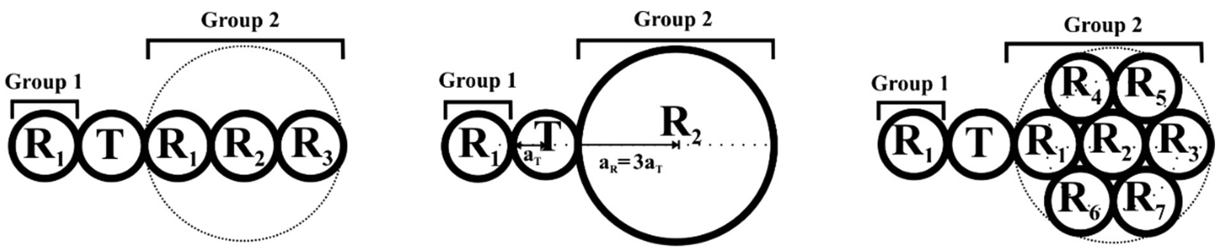

Fig. 1. (a) Type I, (b) Type II and (c) Type III configuration of self-referenced FODS.

in sensitivity is proposed to be done using a self-referencing technique. A novel configuration (Type III) of self-referenced FODS is reported to improve both linear displacement range and sensitivity as shown in Fig. 1(c). In type III configuration, the second receiving group has seven optical fibers which are arranged in a circular fashion. All optical fibers in type III configuration are identical to each other. Similar to the type I and II configuration the self-referencing is done by taking the ratio of receiving fiber outputs from group 2 and group 1. A comparative study of three types of configurations of self-referenced FODS having same geometrical structure has done.

2. Analytical modeling

The geometry of reflective type of fiber optic displacement sensor is as shown in Fig. 2. The light intensity emitted from the transmitting fiber is described with a Gaussian distribution [7].

$$I(r,z) = \frac{2P_E}{\pi\omega^2(z)}\exp\left(\frac{-2r^2}{\omega^2(z)}\right) \tag{1}$$

where P_E is the light power emitted from transmitting fiber, r is the radial coordinate, z is the longitudinal coordinate from the light origin, $\omega(z)$ is the beam waist radius which is a function of z, and

$$\omega(z) = \omega_0\sqrt{1+\left(\frac{z}{z_R}\right)^2}$$

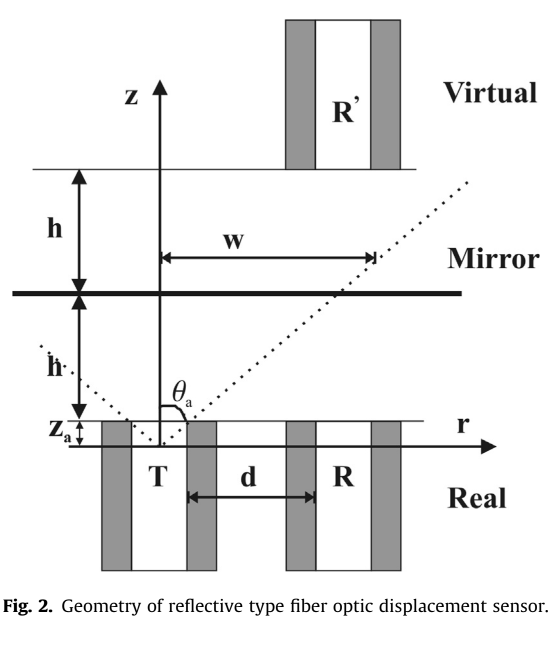

Fig. 2. Geometry of reflective type fiber optic displacement sensor.

The waist radius ω_0 and Rayleigh range z_R are the important parameters in the Gaussian beam function.

The light power collected by the receiving fiber is evaluated by integrating light intensity (I) over the fiber end surface area (S_a),

$$P(z) = \int_{S_a} I(r,z)dS_a \tag{2}$$

However, the exact integration is impossible. Therefore, assumptions and approximations were used to solve the integration. For points situated in the far-field, $z \gg z_R$ the following relations with the divergence angle can be obtained

$$\theta_a = \tan(\theta_a) = \frac{\omega(z)}{z} = \frac{\omega_0}{z_R} = \frac{\lambda}{\pi\omega_0} \tag{3}$$

The core radius of the transmitting and receiving fibers are given by the approximations

$$r_T = z_a\tan(\theta_a) \approx z_a\theta_a \tag{4}$$

and

$$r_R = k_1 r_T = k_1 z_a\theta_a \tag{5}$$

where z_a is the distance between the beam source to the fiber end and k_1 is the ratio of core radius of receiving fiber to core radius of transmitting fiber. The core area of the receiving fiber is calculated as

$$S_a = \pi r_R^2 = \pi k_1^2 r_T^2 = \pi k_1^2 z_a^2\theta_a^2 \tag{6}$$

The radial distance between the two core centers of the transmitting fiber and receiving fiber is determined from

$$r = r_T + r_R + d = r_T + k_1 r_T + k_2 r_T = (1+k_1+k_2)r_T \tag{7}$$

where d is the distance between transmitting and receiving fiber and k_2 is the ratio of the distance between transmitting and receiving fiber to core radius of transmitting fiber.

The path of the beam from the beam source to the bundle end after the reflection is given by,

$$z_a + 2h \tag{8}$$

The displacement parameter in the normalized form is presented as

$$\xi = \frac{z}{z_a} = \frac{z_a+2h}{z_a} = 1 + 2\frac{h}{z_a} = 1 + 2h_N \tag{9}$$

where h is the displacement between reflective mirror to the fiber end and h_N is the normalized distance.

The received power by receiving fiber is given by,

$$P(\xi) = \frac{2P_E k_1^2}{\xi^2}\exp\left(\frac{-2(1+k_1+k_2)^2}{\xi^2}\right) \tag{10}$$