Optik 125 (2014) 126–129

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Improvement of measurement range of optical fiber displacement sensor based on neutral network

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ARTICLE INFO

Article history:
Received 28 January 2013
Accepted 3 June 2013

Keywords:
Measurement range
Optical fiber displacement sensor
Artificial neural network
Compensation

ABSTRACT

By studying the output characteristics of random type optical fiber displacement sensor and semicircular type optical fiber displacement sensor, a sensor of new structure was designed. Using the ratio of the two output signals as the output of the whole system, the measurement range was enlarged, the linearity was improved, and the errors of reflective and absorbent changing in target surface are automatically compensated. Meantime, an optical fiber sensor model of correcting static error and linearizing the output curve based on BP artificial neural network was set up. The intrinsic errors such as fluctuations in the light, circuit excursion, the intensity losses in the fiber lines and the additional losses in the receiving fiber caused by bends were eliminated. By discussing in theory and experiment, the error of nonlinear is 2.9%, the measurement range reaches to 3.0 mm and the relative accuracy is 2%. This kind of sensor offers such advantages as no electromagnetic interference, simple construction, high sensitivity, good accuracy and stability.

1. Introduction

Because of simple construction, low cost, anti-electromagnetic interference and capable of working in bad conditions, optical fiber displacement sensor has a very important status in the area of optical fiber sensing technology and has been used widely these years [1,2]. Just by appropriate improving the structure of basic optical fiber displacement sensor, it can be used to measure many physical quantities such as pressure, temperature, strain, vibration, surface roughness, and so on. Cook and Hamm have made a detailed study of this kind of sensor before [3].

However in general, the measurement range of optical fiber displacement sensor is very limited and the output linearity is not so satisfied [4,5]. According to the typical output characteristic of this kind of sensor, the measurement process is usually confined to the fore slope because of the better linearity and sensitivity, and the measurement range is not more than 1 mm. This has become a serious limitation for applying the sensor more widely. Some researchers have proposed methods to solve the problem by improving the structure or using outside hardware circuit, and could expand the measurement range to same extent [6,7]. However the nonlinearity of the output curve could not be eliminated in most occasions.

In this paper by using random type optical fiber sensor and semicircular type optical fiber sensor to improve the structure, a new kind of optical fiber displacement sensor is designed. The random type and semicircular type optical fiber sensor are almost symmetric in the system by sharing the same light source and using identical photoelectric conversion circuits. The numbers of TR (transmitting fiber) and RF (receiving fiber) in each sensor are also the same, in order to maintain the symmetry of the two sensors. By using the ratio of the output of the two sensors as the whole output function, the measurement range is enlarged. Also an ANN (artificial neural network) model is used to correct static error, such as fluctuations in the light, circuit excursion and the losses in optical fibers. Moreover the ANN model enhances the measuring accuracy and a good linearity of the output curve is gotten.

2. Principle of optical fiber displacement sensor

In general an optical fiber displacement sensor consists of a fiber as a light source (transmitting fiber: TR) and the other as a light receiver (receiving fiber: RF). The transmitting fiber illuminates the reflecting surface and the receiving fiber receives the reflected light [8]. The structure of a basic fiber-optic reflective displacement sensor probe is shown in Fig. 1.

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http://dx.doi.org/10.1016/j.ijleo.2013.06.027

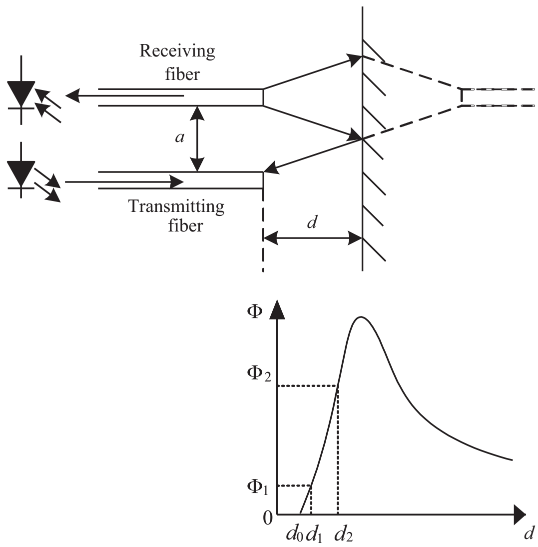

Fig. 1. Construction and output characteristic of basic optic-fiber displacement sensor.

The output light intensity of the receiving fiber is a function of the distance from the reflecting target to the receiving fiber probe. When the distance is within some range, the light intensity and the distance have a good linear relationship.

By measuring the output light intensity of the receiving fiber, we can determine the displacement between the sensor probe and the reflecting target. However the measurement range usually is very limited and the available part is only the fore slope of the curve, because the good linearity is only in this part. The curve of the relationship between the light intensity and the displacement is also shown in Fig. 1.

3. Design of the sensor system

3.1. Design of the optical fiber sensor

We can find the distribution of TF and RF in random type optical fiber sensor and semicircular type optical fiber sensor in Fig. 2. The relationship between the light intensity and the displacement of both kinds of sensors are also shown in Fig. 2. Notably the random type optical displacement sensor has smaller measurement range than the semicircular type, but the sensitivity in its fore slope is better. However the available parts of both types are limited within 1 mm [9,10]. We designed a new optical sensor to enlarge the measurement range by using random type optical fiber sensor and semicircular type optical fiber sensor. The structure is showed in Fig. 2.

The two sensors shared the same light source and used two identical PD to receive the reflective light. By photoelectric conversion and amplifying, the two output signals were performed division operation and got the whole output of the system as shown in Fig. 3.

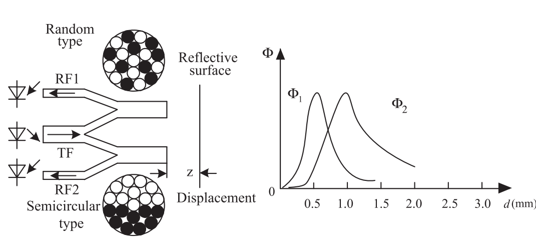

Fig. 2. Structure of the new optical fiber displacement sensor.

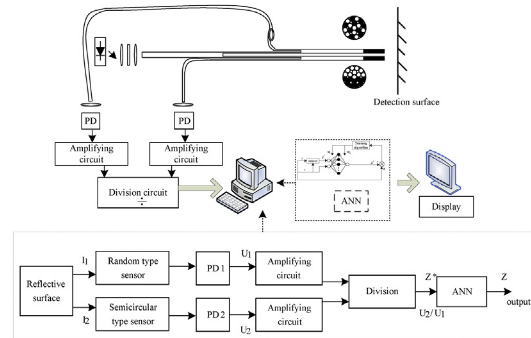

Fig. 3. Diagram of the whole optical fiber displacement sensor system.

The output voltage of each sensor can be expresses as Eqs. (1) and (2).

$$U_1 = I_1 C_1 A_1 K_1 \tag{1}$$

$$U_2 = I_2 C_2 A_2 K_2 \tag{2}$$

where $I_{1,2}$ are intensity of receiving light by RF1 and RF2, $C_{1,2}$, $A_{1,2}$, and $K_{1,2}$ are coefficients of photoelectric conversion, amplifying circuits, and circuit excursion of each sensor.

The intensity of reflected light received by the receiving optical fiber RF1 and RF2 can be illuminated as Eqs. (3) and (4).

$$I_1 = I_{01}\rho_1 K_{01} R_1 \exp_1(-\xi, z) f_1(z) \tag{3}$$

$$I_2 = I_{02}\rho_2 K_{02} R_2 \exp_2(-\xi, z) f_2(z) \tag{4}$$

where I_{01}, I_{02} are the amount of light sources in two sensors, $K_{01,02} = K_1 K_2$, and K_1 is the coefficient of light source excursion, K_2 is the additional losses in the optical fibers, $R_{1,2}$ is the roughness coefficient of target surface, $\rho_{1,2}$ and $\xi_{1,2}$ are the reflecting coefficient and absorbent coefficient of the reflective surface, z is the displacement from the reflective surface to the probe. Therefore the output voltage of two sensors can be written as Eqs. (5) and (6).

$$U_1 = C_1 A_1 K_1 I_{01}\rho_1 K_{01} R_1 \exp_1(-\xi, z) f_1(z) \tag{5}$$

$$U_2 = C_2 A_2 K_1 I_{02}\rho_2 K_{02} R_2 \exp_2(-\xi, z) f_2(z) \tag{6}$$

Because of the symmetry and the same numbers of the TF and RF of the two sensors, the coefficients in the two sensors are almost the same magnitude except K and $f(z)$.

When we use a division device to get the output as shown in Fig. 3, U_2/U_1 is reduced to

$$\frac{U_2}{U_1} = \frac{C_2 A_2 K_2 K_{02} f_2(z)}{C_1 A_1 K_1 K_{01} f_1(z)} \tag{7}$$

It can be noticed that because of the coefficients are all constants, the ratio output is independent of other factors and is a function only of the distance z. The roughness, reflective and absorbent changing in target surface are automatically compensated.

3.2. Mathematic model of correcting static error and linearizing output function based on BP artificial neural network

Although using the ratio of the output of the two optical sensors as the whole output function can eliminate some errors, there are still some other factors such as circuit excursion and light source excursion. Therefore an optical fiber sensor model of correcting static error and linearizing the output curve based on BP artificial neural network (ANN) is set up in this paper.

It has been proved that an artificial neural network of three layers can approach any continuous nonlinear function [11]. We chose