DISPLACEMENT MEASUREMENT USING OPTICAL FIBER REFLECTION SENSORS

Alojz Suhadolnik, Jože Petrišič

Faculty of Mechanical Engineering, University of Ljubljana, Slovenia

Key words: light emitting sensors, optical fibers, optical fiber sensor, displacement measurements, intensity sensor, reflection sensor

Abstract: Optical fiber reflection sensors for the displacement measurement are described. We tested different optical fiber reflection sensors configurations. The displacements are measured by approaching the optical fiber tip toward reflective surface and by moving it parallel to the surface. Various sensor responses are detected by using an optical power meter and analyzed with the computer.

Merjenje pomika z uporabo odbojnostnih senzorjev z optičnimi vlakni

Ključne besede: svetlobni senzorji, optična vlakna, senzorji z optičnimi vlakni, merjenje pomikov, intenzitetni sensor, odbojnostni senzor

Izvleček: Opisani so odbojnostni senzorji z optičnimi vlakni za merjenje pomikov. Preizkusili smo različne konfiguracije odbojnostnih senzorjev z optičnimi vlakni. Princip delovanja sloni na približevanju ali vzporednemu gibanju senzorske konice glede na površino, ki svetlobo odbija. Signale smo izmerili s pomočjo optičnega merilnika moči in analizirali z uporabo računalnika.

1. Introduction

Several optical fiber sensors for the displacement measurement have been designed /1/. Most of them are based on the optical intensity variation. An optical fiber microbanding sensor was developed for measuring the displacement /2/. The optical fiber interferometers measure small displacements and vibrations with high precision /3/. The reflective type optical fiber sensors are also described /4/. They can be used for the sound detection as a microphone /5/. We measured refractive indexes of fluids using this kind of the fiber optic sensor /6/. They are simple in construction and could be used in explosive environments. In this paper we shortly describe an intensity displacement fiber optic sensor with two parallel fibers. In addition we describe the optical fiber sensor with a circular input optical fiber and a ring type output optical fiber. The displacement measurements were performed by approaching the fiber tip toward the reflective surface and by moving the sensor parallel to the surface where we used a surface with two different reflexive layers.

2. Principles of operation

The optical fiber reflection sensor in general consists of two multimode optical fibers. Both fibers are bound together in a sensor tip. The first fiber is the incoming one and the second is the outgoing (Fig.1). A maximum angle Θ_{NA} within which the light leaves the output fiber at the sensor tip is equal to

$$\Theta_{NA} = \arcsin(NA), \tag{1}$$

where NA is numerical aperture of the optical fiber.

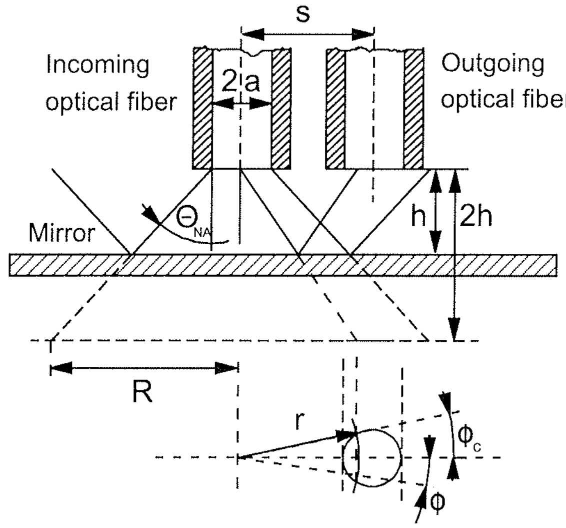

Fig.1. Schematic of the sensor

If P_t denotes the total optical power transmitted through the incoming fiber and $P_o(2h)$ the captured power by the outgoing fiber, then the efficiency factor $\eta(2h)$ at the distance h between the fiber tip and the reflective surface is equal to

$$\eta(2h) = P_o(2h)/P_t \,. \tag{2}$$

If we assume that the far field optical intensity distribution at the incoming optical fiber tip $I(r,2h)$ is parabolic,

$$I(r,2h)=\frac{2P_i}{\pi R^2(h)}\left(1-\frac{r^2}{R^2(h)}\right), \quad (3)$$

then we can write

$$\eta(2h)=2\int_{R_1}^{R_2}\int_{0}^{\phi_c} R_s T_i T_o(r,2h)\frac{I(r,2h)}{P_i} r\, \mathrm{d}\phi\, \mathrm{d}r, \quad (4)$$

where R_s is surface reflectivity, T_i and T_o the Fresnel transmittance coefficients of the incoming and outgoing optical fibers /6/. In this equation R is the radius of the light cone at the distance $2h$ and h is the distance between the mirror and the sensor tip

$$R=a+2h\ \ tg(\Theta_{NA}). \quad (5)$$

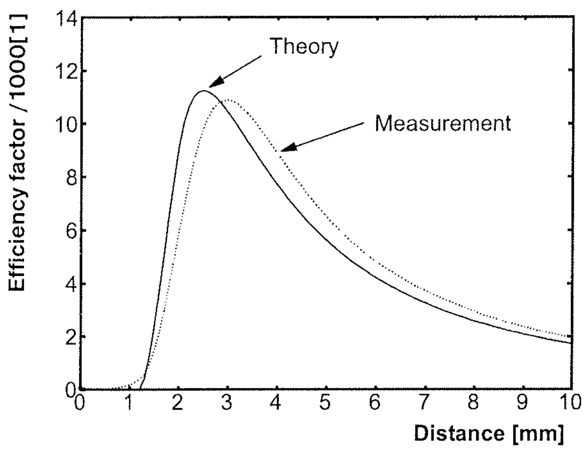

Fig.2. Theoretical and experimental sensor response in moving the sensor tip outward the mirror.

The maximum azimuth angle ϕ_c is equal to

$$\phi_c=\arccos((s^2+r^2-a^2)/(2rs)), \quad (6)$$

where s is the distance between the fiber core axes and a the optical fiber core radius.

The first integration limit R_1 in the integral (4) is $R_1 = s - a$ if $R > s - a$ otherwise $R_1 = 0$. The second limit R_2 is equal to $R_2 = s+a$ if $R \geq s+a$ and $R_2 = R$ if $s - a < R < s+a$ otherwise $R_2 = 0$.

In Fig. 2 the theoretical efficiency and the experimental curves are shown. The sensor consists of two identical optical fibers. The optical fibers used had a core radius a = 0.5 mm, s =2.2 mm and NA=0.47.

3. Ring type sensor

In this section a ring type sensor is described. The schematic of this sensor is shown in fig.3.

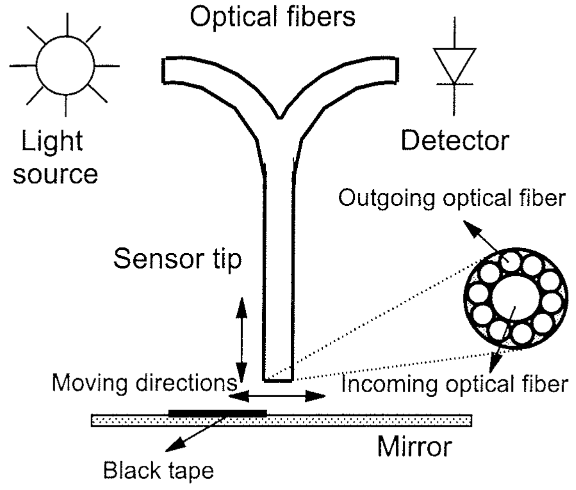

Fig.3. Ring type optical fiber reflection sensor

The ring type sensor has one incoming optical fiber and several small fiber fragments arranged in a ring around the incoming optical fiber. The ring shaped fiber fragments are gathered in the outgoing optical fiber. This type of the sensor tip is capable of collecting more light than the reflection sensor with the two circular optical fibers. We used the red LED as the light source and optical power meter as the detector. The measured results were transferred to the computer for further analysis.

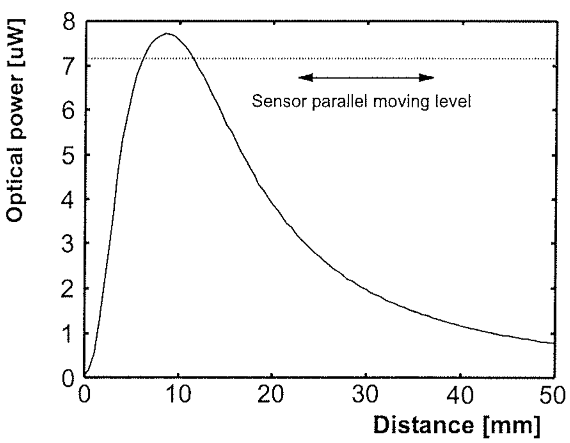

Fig.4. Sensor response for the ring type optical fiber reflection sensor

The sensor response by moving the sensor outward the reflective surface is shown in Fig.4. The ring type optical fiber sensor consists of the same type of the optical fibers as in the previous configuration. In addition we measured the sensor characteristics by moving the sensor tip parallel to the reflective surface. One part of the reflective surface was covered with the black color type. The reflectance upon the colored part of the surface is much smaller. In Fig. 5 the sensor response is shown.

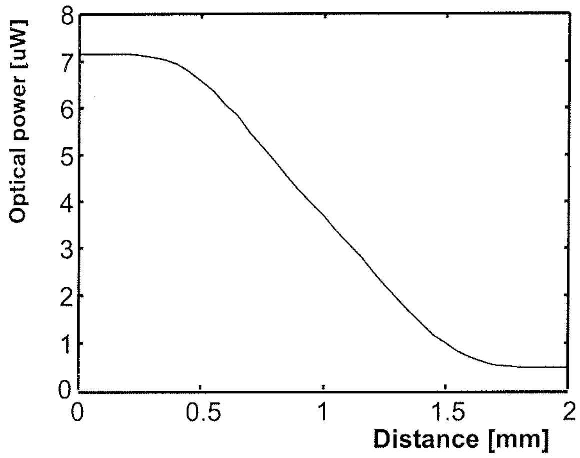

Fig.5. Sensor responses by moving the sensor tip parallel to the surface.

The sensor tip is close to the surface where the sensor response is near the maximum. The sensor characteristic decrease rapidly when the sensor tip passes over the color border. It can be seen from Fig. 5 that the sensor response is linear within 1 mm. We used this sensor for monitoring an electro welding head displacement.

4. Conclusions

This paper describes two types of optical fiber reflection sensors. The first one consists of two fibers and the second one is a ring type optical fiber sensor. The sensors working principles are evaluated as well as the sensors characteristic responses. Those sensors are capable of measuring a position of a few millimeters and detecting the displacement of the objects with the different surface reflectivity.

References

/1/ E. Udd, Fiber optic sensors, John Wiley & Sons, New York, 1991

/2/ W. H. G. Horsthuis, J. H. J. Fluitman, The development of fibre optic microbend sensors, Sensors and actuators, 3, 1982/83, 99-110

/3/ A. D. Drake, D. C. Leiner, Fiber-optic interferometer for remote subangstrom vibration measurement, Rev. Sci. Instrum., Vol. 55, No. 2, 1984, 162-165

/4/ R. O. Cook, C. W. Hamm, Fiber optic lever displacement transducer, Appl. Opt. 18, 1979, 3230-3241.

/5/ A. Suhadolnik, A. Babnik and J. Možina, Microphone based on fibre optic reflective sensor, Europto, Fiber Optic and Laser Sensors XIII, SPIE Vol. 2510, Munich, FRG, Jun 20-21, 1995, 120-127

/6/ A. Suhadolnik, A. Babnik and J. Možina, Optical fiber reflection refractometer, Sensors and Actuators B, B29 (1995) 428-432.

dr.Alojz Suhadolnik and dr.Jože Petrišič
Faculty of Mechanical Engineering
Aškerčeva 6
1000 Ljubljana
Slovenia
E-mail: alojz.suhadolnik@guest.arnes.si
joze.petrisic@fs.uni-lj.si

Prispelo (Arrived): 30.05.2002 Sprejeto (Accepted): 28.06.2002