Fiber Optic Lever Displacement Transducers: Principles, Improvements, and Applications

Introduction

The recent flurry of activity in fiber optic sensors has resulted in a great variety of technically sophisticated devices employing interference, polarization and wavelength modulation techniques [1]. While all of these methods offer great promise for certain specific applications and dedicated sensors, the intensity modulated Fiber Optic Lever Displacement Transducer offers a powerful combination of simplicity, performance, versatility, and low cost, which make it well suited for a wide variety of laboratory and industrial applications.

The Principle

The basic principle employed in the Fiber Optic Lever Displacement Transducer comes down to the use of an adjacent pair of fiber optic elements, one to carry light from a remote source to an object or target whose displacement or motion is to be measured and the other to receive the light reflected from the object and carry it back to a remote photo sensitive detector. A complete analysis of the principles and performance characteristics of this type of transducer was done by R.O. Cook and C.W. Hamm [2]. A fiber optic element is a flexible strand of glass or plastic capable of transmitting light along its length by maintaining near total internal reflection of the light accepted at its input end, as shown in Fig-1.

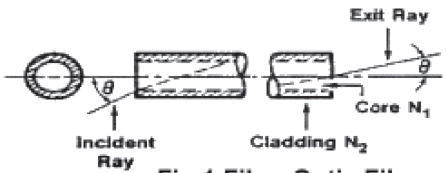

Fig.1 Fiber Optic Filament

The most commonly used fibers are called “step index” type and consist of an inner core to carry the light flux and an outer cladding. For total internal reflection to occur, the index of refraction of the glass in the core (NI) must be greater than the index refraction of the glass cladding (N2). The sine of the half angle of the light which will be accepted into the core is defined as the numerical aperature (N.A.) and is given by the formula:

$$N.A. = \text{Sin } 0 = \sqrt{(N_1^2 - N_2^2)}$$

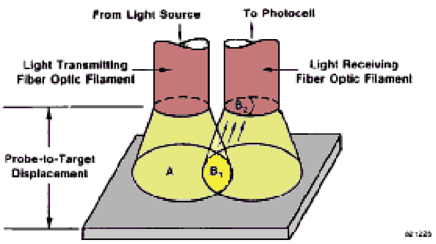

Fig. 2 Target Moving Away from Probe – Reflected Light Intensity Increases

This is the maximum angle at which a light ray incident on the face of the fiber can be trapped within the core and reflected along its length. The light rays then exiting the other end of the fiber are also limited to the same angle. Individual fibers usually fall in the range of about 0.001” diameter to .010” diameter although recent advances in the fiber optic manufacturing technology has extended the size up to about .060”. Transmission efficiency is dependent upon the composition and purity of the glass used in the core and cladding and on the quality of the optical finish on the end surfaces of the fibers.

Fig. 2 depicts the interaction of adjacent transmit and receive fibers as the light is reflected from a target. It can be seen that at zero gap, the light in the transmit fiber would be reflected directly back into itself and little or no

MTI Instruments, Inc.
325 Washington Avenue Extension
Albany, NY 12205
PH: +1-518-218-2550
OR USA TOLL FREE: 1-800-342-2203
FX: +1-518-218-2506
sales@mtiinstruments.com
www.mtiinstruments.com

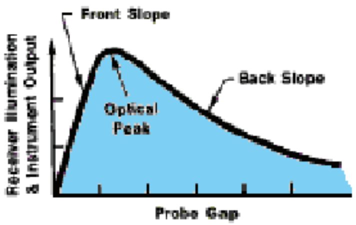

Fig. 3 Typical Fiber Optic Sensor Calibration Curve

light would be transferred to the receive fiber. As the gap increases, some of the reflected light is captured by the receive fiber and carried to the photo-sensitive detector. As the gap increases, a distance will be reached at which a maximum of reflected light is transferred to the receive fiber. Further increases in the gap will result in a decrease in the light at the receiver fiber face and a corresponding drop in the output signal from the photo sensor.

Operation

A major advantage of the fiber optic lever transducer (FOTONIC SENSOR) is its ability to operate directly with a large variety of surfaces, from specular to diffuse, and materials from conductors to insulators.

As shown in Fig. 3, the gap and displacement range over which the initial rise in signal takes place and at which the maximum occurs is primarily determined by the diameter and the N.A. of the fibers and the intensity distribution within the operating field of the fibers. Most commercial devices of this type use multiple transmit and receive fibers, as shown in Fig. 4 in order to obtain the higher levels of intensity at the photo detectors needed to insure acceptable levels of performance.

The reference by Hoogenboom, and Allen & Wang,[3] gives additional information on theoretical and experimental verification of the response characteristics of multiple fiber transducers.

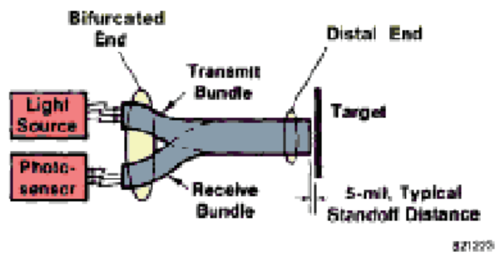

Fig. 4 Fiber Optic Probe

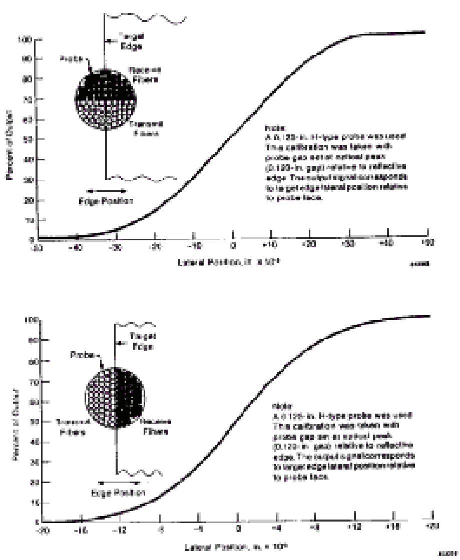

Fig. 5 Output vs Lateral Edge Position - Edge

The gap at which the maximum, or zero slope occurs, provides a convenient and readily usable calibration reference position at which the output signal can be normalized in order to obtain a consistent sensitivity factor relatively independent of the color or finish of the surface of the target or object under measurement.

Since the maximum output position also offers an operating point at which the output signal is independent of gap over a certain range, it also gives the user an additional mode of operation which permits measurement of lateral position and displacement of an object having a sharply defined edge or reflective interface, as shown in Fig. 5.

This same zero slope, or optical peak as it is referred to in most literature, also provides a means of measuring reflectance of the target independent of gap changes over some displacement . Thus through the use of sophisticated signal conditioning equipment can be used to derive static or dynamic measurements of position or displacement which are corrected for reflectance variations which would otherwise cause error and uncertainties in the data. Fiber Optic Lever Displacement Transducers of sizes, configurations, are available in a great variety and fiber distribution patterns [4] giving the user a broad choice of sensing range, resolution, frequency response, physical shape, etc.
ter fibers with a .62 N.A., and having a random,or thoroughly intermixed array of transmit and receive fibers calibrated in air, water, and motor oil. The inherent simplicity, versatility, and ease of use of the Fiber Optic Lever Displacement Transducer plus its small physical size, its fast response, its non-contact no mass loading, and its E.M.I. immunity has found many applications in the field of position displacement and vibration measurements.

Variations

An interesting and very useful variation on this device is obtained when a focusing lens system is placed near the sensing end of the fiber optic probe.[5] The results of one such combination of lenses and fiber optics is shown in Fig. 6. As can be seen, two optical peaks are now present with a sharp null occurring midway between the peaks. Either of steep response areas each side of the null point can be used to measure small displacement, high resolution applications while operating at nearly 100 times normal operating gap. A novel, self-focusing continuous tracking optical measurement system has been built utilizing this combination of elements and its characteristic sharp null point.[6]

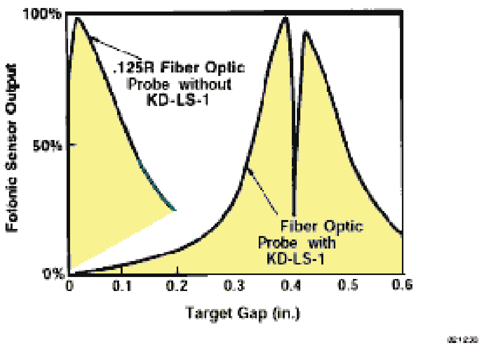

Fig. 6 KD-LS-1 Output with Probe

Another variation of the Fiber Optic Lever Displacement Transducer can be derived by utilizing a fiber optic sensor which has two receive channels supplied by a common transmit bundle. The fiber size and distribution with the receive channels are designed to generate different optical lever responses and thus can be ratioed to provide an output signal directly independent of surface reflectivity.[4]

An unusually novel form of Fiber Optic Lever Transducer employs a pair of large diameter fibers whose axis are inclined at an angle relative to one another rather than parallel as in other forms of this device[7]. The Fiber Optic Lever Displacement Transducer can be operated with liquids as well as air or other gases in the sensing gap.

Fig. 7 shows the response curve of a fiber optic probe employing .0025" diameter fibers with a .62 N.A., and having a random,or thoroughly intermixed array of transmit and receive fibers calibrated in air, water, and motor oil. The inherent simplicity, versatility, and ease of use of the Fiber Optic Lever Displacement Transducer plus its small physical size, its fast response, its non-contact no mass loading, and its E.M.I. immunity has found many applications in the field of position displacement and vibration measurements.

Applications

Some examples of applications which the Fiber Optic Lever Transducers has been used for and which the users have taken the time to disclose are as follows:

+ Modal Analysis of small lightweight parts or mechanisms such as Hard Disk
+ Drive read/write head and flexure assembler. [8]
+ Performance Investigation of Rolling Element Bearings. [9]
+ Measurement of very high frequency, small amplitude vibrations such as ultrasonically driven medical devices or welding equipment. [10]
+ Development of Fast Response Pressure Transducer for Use In Shock Tube and Electrical Discharge Environment. [11]
+ Bearing health monitoring of rotating equipment operating in liquid oxygen environment. [12]
+ Repeatability, hysteresis, and response time of precision mechanical mechanisms, or piezoelectric micropositioners. [13]

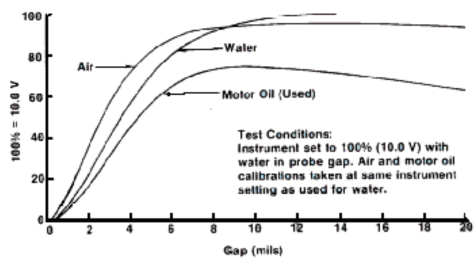

Fig. 7 Fiber Optic Lever Displacement Transducer with 0.0025 in., 0.62 N.A. Fibers; 0.086 in. Diameter Bundle Size

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