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Regular

Underwater Fiber Optic Sensor for Detecting of Acoustical Wave Disturbance by Using Single Mode Optical Fiber

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Abstract : In this paper, phase difference measurement caused by acoustical wave disturbance examined by using straight optical fiber cable as a measurand. A single mode optical fiber and underwater acoustical wave transducer was used in the experiment. The output result of the optical fiber cable is connected to a photon counter to performing the Poisson distribution.

Keywords : fiber optic sensor, acoustical wave disturbance, photon counting, single mode optical fiber

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1 INTRODUCTION

1.1 Consideration

Basically, there are two main types of fiber optic sensors used today. They are phase modulated and intensity modulated sensors. Intensity modulated sensors works by letting a physical disturbance cause a change in the received light through an optical fiber [1]. Phase modulated sensor works by comparing phase of light in the sensing fiber with a reference.

Fiber optic sensors are also classified as extrinsic and intrinsic. In an intrinsic, the fiber itself is the sensing element (fiber directly affected by measurand) and in extrinsic, a fiber simply transports light to or from the sensing element. Compared with other types of sensors, some of other main advantages are their high sensitivity and possibility to measure in hostile environment [2] (heat [3], dangerous, chemical, etc). This paper intends to present a phase difference caused by underwater acoustical wave disturbance. The measurement has been done in a water chamber where is installed a water acoustical wave transducer.

1.2 Intensity modulated sensor

An intensity-modulated sensor must change the intensity of the measurand light in a way that can be predicted. There are several ways of achieving this. The simplest one is transmission or reflection concept. Other concepts are those of microbending intrinsic sensors.

Transmission or reflection concept is normally used as a digital switch but can also be used as an analogue detector. It works by simply moving the detector or a mirror a distance radius away from the fiber center.

When optical fiber is bent, small amounts of light will be lost as the angle of incident between transmitted light and fiber walls change due to loss of total internal reflection. This is called microbending and is a way to detect a displacement in a closed optical path. As the path is closed, microbending optical sensor can be used in dirty environments.

The intrinsic sensors have the advantage as the intensity can be changed without any actual movement of the fiber. Instead, they used the chemically changing in it refractive index, absorption through the walls or polarization to caused change in intensity.

1.3 Phase modulated sensors

Phase modulated sensors consist in general of a coherent laser which inject light into single mode fiber. If the environment perturbs fiber path, a phase shift will occur that can easily be detected. Even an extremely

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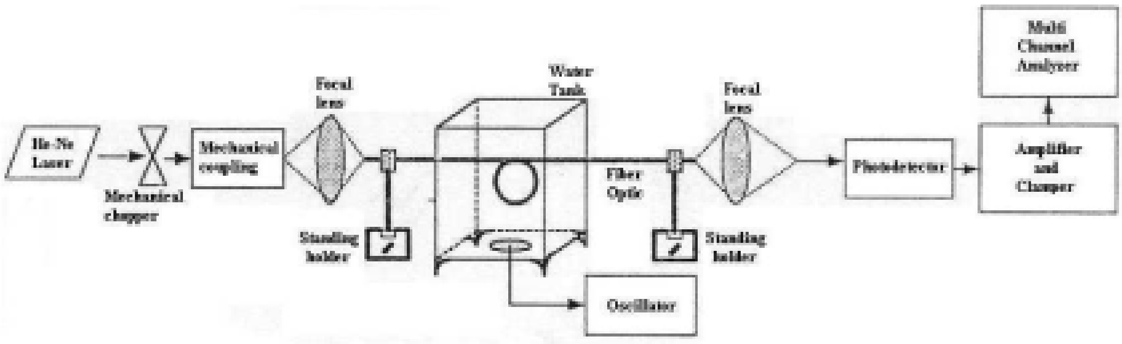

FIGURE 1: Simple fiber optic sensor For acoustical wave detection [4].

small perturbation will be possible to detect using by a single mode optical fiber.

2 THE PHASE DIFFERENT DETECTION

2.1 Introduction

The intrinsic of fiber optic sensor is used for detecting of underwater acoustical wave disturbance. Modulation that is used to code phase different information may be considered. The photon counting performs information result. A simple but useful fiber optic phase different sensor is shown in Fig. 1. Basic ideas are putting the fiber and acoustic wave transducer in a water chamber. A function generator generates the acoustic wave input to a transducer.

Phase different information is performed from the mechanic chopper. The light source is coupled with a mechanic coupler Newport F-1015LD.

2.2 Theory

The phase of the light transmitted through a single mode fiber is presented by,

$$\phi = \beta L + \varphi_i \ , \tag{1}$$

where β is the propagation constant, φ_i as the initial phase of the light at the input end of a fiber and as the fiber length. When the acoustic wave is varied the phase shift of the light transmitted through a fiber per unit length and small variation ∂f is obtained by,

$$\frac{1}{L}\frac{\partial \phi}{\partial f} = \frac{\beta}{L}\frac{\partial L}{\partial f} + \frac{\partial \beta}{\partial f} \ , \tag{2}$$

where $\partial L/\partial f$ is the acoustical expansion constant to be zero. Eq. (2), well known as sensor sensitivity, it could be written by,

$$\eta = \frac{1}{L}\frac{\partial \phi}{\partial f} = \frac{\partial \beta}{\partial f} \ . \tag{3}$$

Assuming that core and cladding have acoustical optic coefficient (τ), it is defined as follows,

$$\tau = -\frac{1}{n_j}\frac{\partial n_j}{\partial f} \ , \tag{4}$$

where n_j ($j = 1, 2$) represented core and cladding refractive index. The number of V is defined as the propagated number of mode, and

$$V = k_o \alpha \sqrt{n_1^2 - n_2^2} \ , \tag{5}$$

where k_o is the wave number in free space, n_1 and n_2 are the refractive index of the core axis and cladding axis respectively, α is the core radius. The weakly guiding fiber is represented by,

$$\Delta = \frac{n_1 - n_2}{n_1} \ , \tag{6}$$

and the Eq. (5) could be written back as,

$$V = n_1 k_o \alpha \sqrt{2\Delta - \Delta^2} \ . \tag{7}$$

Further, the number of propagation constant on the cladding is defined by,

$$\gamma = \frac{V\sqrt{b}}{\alpha} \ , \tag{8}$$

then

$$\gamma = k_o \sqrt{\left(n_1^2 - n_2^2\right) b} \ . \tag{9}$$

Therefore the propagation constant b could be written a simply from,

$$\beta^2 = k_o^2 \left[n_2^2 + b \left(n_1^2 - n_2^2 \right) \right] \ , \tag{10}$$

and finally,

$$b = \frac{\beta^2 - k_o^2 n_2^2}{k_o^2 \left(n_1^2 - n_2^2 \right)} \ . \tag{11}$$

By substituting this equation into the function, we find

$$\frac{\partial \beta}{\partial f} = \beta\tau + k_o^2 \left(n_1^2 - n_2^2 \right) \frac{1}{2\beta}\frac{\partial b}{\partial V}\frac{\partial V}{\partial f} \ . \tag{12}$$

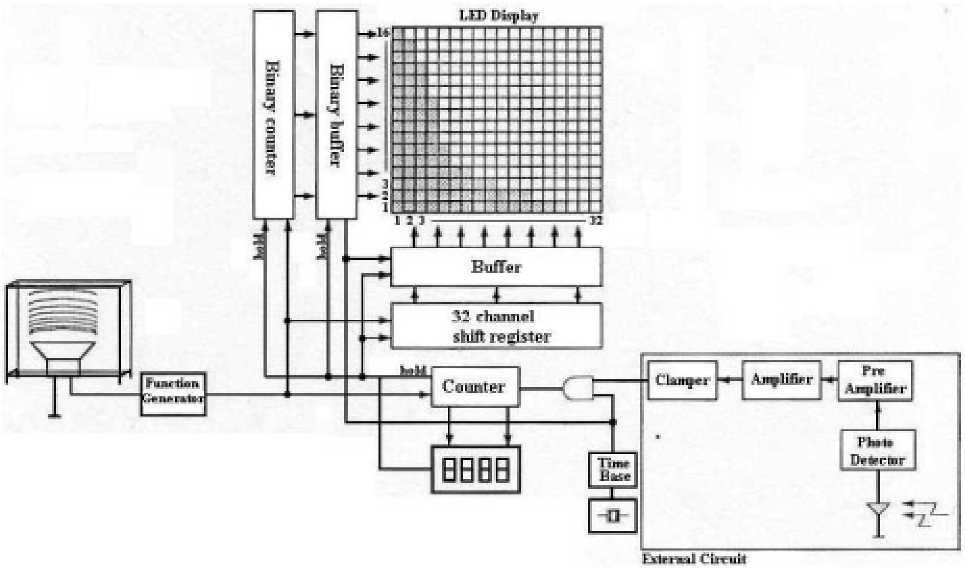

FIGURE 2: The scheme block of the photon counter [5].

Combining with Eq. (5), the f function changes to

$$\begin{aligned}\frac{\partial V}{\partial f} &= k_o\frac{\partial \alpha}{\partial f}\sqrt{n_1^2-n_2^2} \\ &+\frac{k_o\alpha}{\sqrt{n_1^2-n_2^2}}\left(2n_1\frac{\partial n_1}{\partial f}-2n_2\frac{\partial n_2}{\partial f}\right) .\end{aligned} \tag{13}$$

Due to $\partial\alpha/\partial f = 0$, Eq. (13) could be written in the form as,

$$\frac{\partial V}{\partial f} = \left(k_o\alpha\sqrt{n_1^2-n_2^2}\right)\tau = V\tau , \tag{14}$$

and by using Eq. (12), it becomes

$$\frac{\partial \beta}{\partial f} = \beta\tau + \frac{k_o^2\left(n_1^2-n_2^2\right)}{2}\frac{1}{\beta}\frac{\partial b}{\partial V}\frac{\partial V}{\partial f} . \tag{15}$$

The sensing sensitivity of sensor is given by,

$$\eta = \beta\tau + \frac{k_o^2\left(n_1^2-n_2^2\right)}{2}\frac{1}{\beta}\frac{\partial b}{\partial V}V\tau . \tag{16}$$

2.3 Photon counting

A scheme containing the essential elements of the group photoelectron distribution counter is given in Fig. 2. The most direct measurement can be performing by counting the number n of pulse that collected in a given single time interval τ. A fast electronic digital counter conveniently does it, whose the output of this counter is transferred into a multichannel analyzer and display on the dot matrix light emitting diode display.

If n is the number of pulses in a single time interval τ, it will be transferred as a single count in the nth channel of the channels counter and display of the multichannel analyzer circuit. n varies from one up to a maximum value of $n_{\max}$ (the instrument is designed for $n_{\max} = 32$). So that the number n is a statistical variables. Hence the probability distribution of counts $P(n,\tau)$ has to be obtained from a large set of measurements and performed under identical condition in order to approach a statistical ensemble. If k_o is the number of recorded event in nth channel of the channel display and $N = \sum k_o$ is the total number of record event, the probability distribution $P(n,\tau)$ is given in the form,

$$P(n,\tau) = \frac{k_o}{N} , \tag{17}$$

where $P(n,\tau)$ is essentially correspond to the statistical properties of the input signal, i.e. the incident optical field under observation. The mean number of counts is given in the form,

$$\langle n\rangle = \sum_{i=1}^{n_{\max}} n_i P(n_i,\tau) , \tag{18}$$

which is proportional to the intensity of the incident optical field and its variance of the number of counts

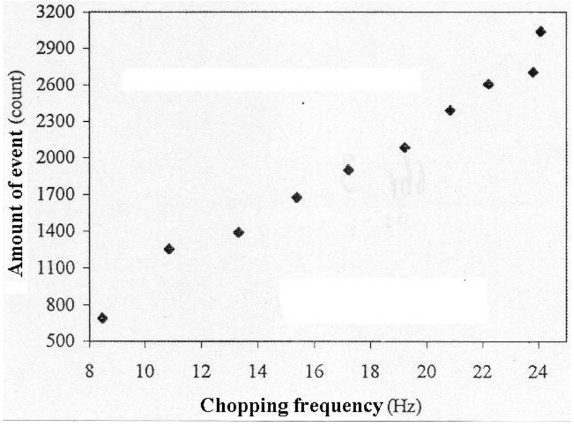

FIGURE 3: Graphic of amount of event to chopping frequency [4].

is given by,

$$\langle \Delta n^2 \rangle = \langle n^2 \rangle - \langle n \rangle^2 \ , \tag{19}$$

where

$$\langle n^2 \rangle = \sum_{i=1}^{n_{\max}} n_i^2 P(n_i, \tau) \ , \tag{20}$$

It is a mean square of the number of counts.

The probability is found as amount of photoelectron that could be counted by the detector, it's using by the Poisson statistic that is written as,

$$P(n_i, \tau) = \frac{(\bar{r}\tau)^n \, e^{\bar{r}\tau}}{n!} \ , \tag{21}$$

where P is the photocounting distribution probability, n is amount of counting and τ is the interval sampling time. Every counting is represented with $n_1, n_2, n_3, \cdots, n_{\max}$.

The receiving intensity has been proportionally with electric current of the detector. By using the resistance in photodetector, it is could be produced electric voltage and electric power. Therefore, to detect amount of the mean of the electron could be written as,

$$\bar{r} = \frac{\eta P}{h\nu} \ , \tag{22}$$

where $\bar{r}$ is amount of the mean electron received, P is power received by the detector (watt), η is quantum effeciency that defined as fraction or a part of effective power from the electron transmitted, $h\nu$ is photon energy received in joule, h is Planck constant and ν is frequency that it is as same as with c/λ, where λ is the wavelength of the laser source.

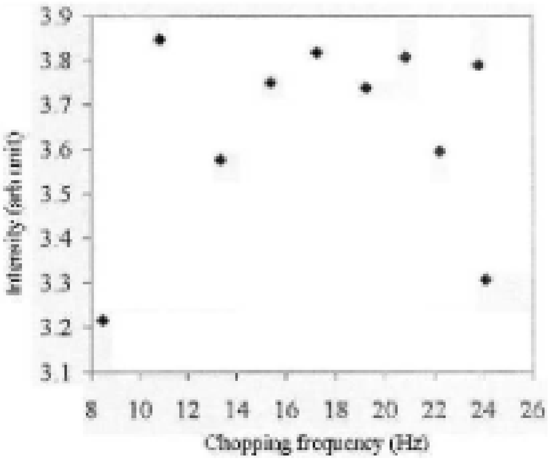

FIGURE 4: Graphic of chopping frequency to intensity [4].

3 EXPERIMENT RESULT AND ANALYSIS

3.1 The undisturbance sensing

The experiment results are shown that the total amount of event should be increase as compare as the chopping frequency increment, it's described in Fig. 3. Fig. 4 shown the graphic of intensity to chopping frequency that performed a parabolic scheme.

3.2 The disturbance sensing

Fig. 5 is shown as the total amount of event to the chopping frequency, included disturbances frequency variance.

As same as Fig. 6 described the intensity with disturbances frequency variance. Comparing Fig. 4 and Fig. 6 shows a parabolic graphic scheme more widely.

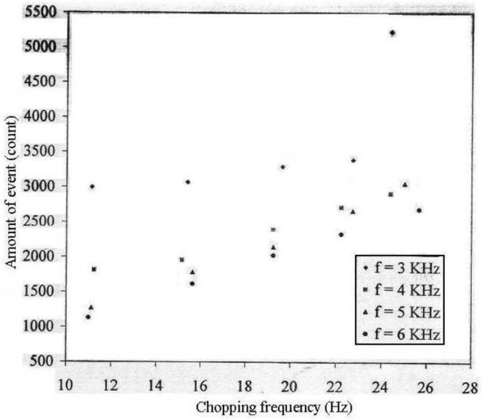

FIGURE 5: Graphic amount of event to chopping frequency with external frequency disturbances [4].

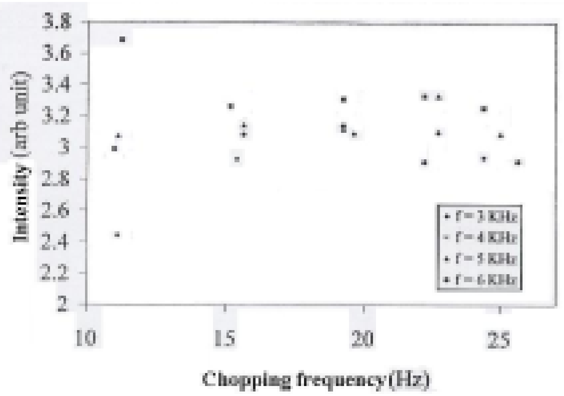

FIGURE 6: Graphic of chopping frequency to intensity [4].

The effect of disturbance frequency could be reduced the event of photon.

3.3 Photo counting display

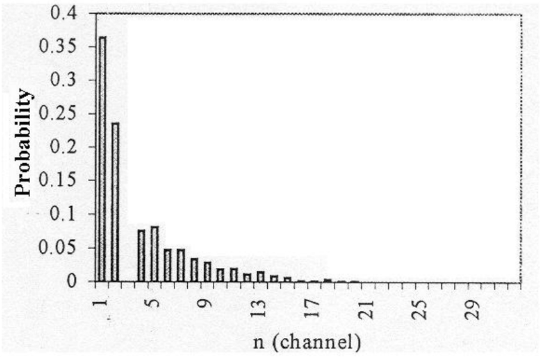

FIGURE 7: Photon counter result with chopping frequency 15 Hz without external frequency disturbance [4].

Fig. 7 and Fig. 8 are shown as photon counter display. It is performed the Poisson distribution. These figure have been giving the change scheme caused frequency disturbances.

4 CONCLUSION

1. In Fig. 9, the experiment is using the chopping frequency 15 Hz. It is a source frequency that is suitable with frequency detection on photon counter. The time detection is defined as,

$$\begin{aligned} t_d &= \text{amount of total counting} \\ &\quad \times\text{smaller sampling time} \\ &= 10^4 \times (2 \times 10^{-6})\text{sec} = 0.02\text{sec}. \end{aligned}$$

   And the frequency detection is used 50 Hz. The number of frequency detection is $f_d \gg 2f_s$. Referred to Fig. 9, the linearity graphic of phase different, it has determined the sensitivity 0.2051 rad/Hz with data elevation angle is 11.59^o. The changing coefficient of optical fiber caused frequency disturbances is 0.059, then the different of refractive index effective $(\partial n_{\text{eff}}/\partial f)$ and acousto-optic coefficient (τ) are 0.0221×10^{-7} and -0.01526×10^{-7} respectively.

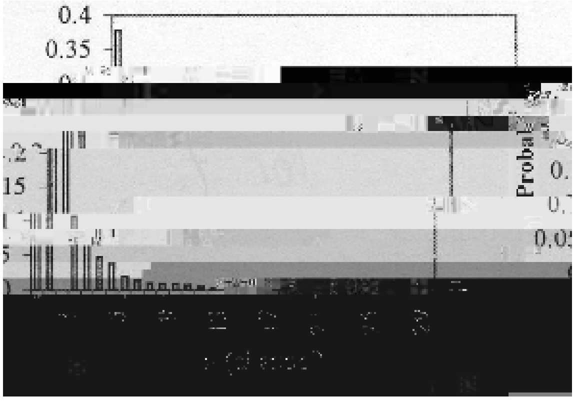

FIGURE 8: Photon counter result with chopping frequency 15 Hz with external frequency disturbance 3 KHz [4].

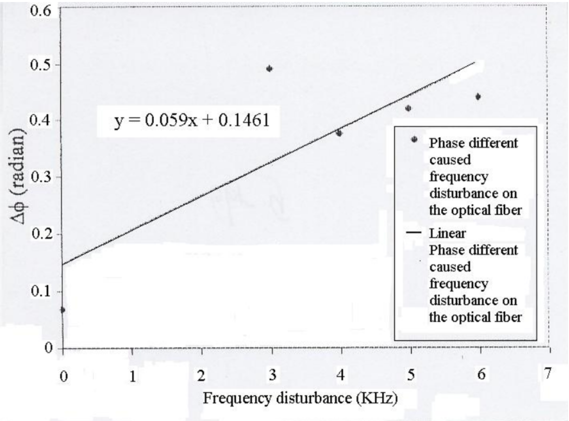

FIGURE 9: The linearity graphic of phase different to frequency disturbance [4].

2. In Fig. 10, the phase difference will be happened if restriction is given to optical fiber on dynamic range between 0 ∼ 4.473 KHz. The phase difference has already happen when there was no restriction at 0.0794 radian as a result of the loss of the optical fiber. At 4.473 KHz or at the peak of frequency, the phase difference are happening on 0.4517 radian.

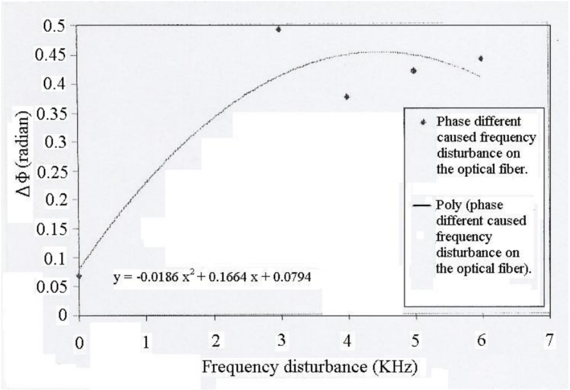

FIGURE 10: The polynomial graphic of phase difference to frequency disturbance [4].

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