Robust Fiber Optic Displacement Sensor Design Using Taguchi Method

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Abstract: This paper presents a new design and implementation of robust two-fiber intensity modulated Fiber Optic displacement Sensor. Taguchi method is applied for robust design of fiber optic sensor development and experimented. The displacement sensor orientations are focused with respect to internal light intensity reflection principle. The basic geometrical parameters of two-fiber sensor such as separation, offset and angle between the fibers are the control parameters and the angle of the reflector is the noise parameter for optimization of the sensor parameter design process. Finally data analysis was carried out for sensitivity and range to predict the sensor performance. It has been observed that this methodology is just not only suitable for designing displacement sensor geometry like structures but also are applicable and useful for other fiber optic based principle.

Key words: Taguchi Method, Robust design, orthogonal array (OA), Fiber optic displacement sensor (FODS), intensity modulation, Inter-fiber angle.

I. INTRODUCTION: Communications grade optical fibers, developed in the early 1970s, and were born out of the demand to carry large amounts of information quickly and economically. Fiber optic sensors are a growing field spawned by the tremendous advances in optical fiber fabrication. Fiber optic sensors are being deployed to measure pressure, temperature, strain, acoustic waves, electromagnetic fields and various chemical and biological agents in a variety of industrial environments, including in oil wells at depths of over10,000 feet; in jet engines, to monitor both test and in-flight parameters; in power transformers, to monitor dielectric breakdown; in civil structures, to monitor bridges and buildings; and along railroad systems, to monitor track integrity, to name just a few[1]. Fiber optic sensors possess a number of unique advantages including immunity to electromagnetic interference, small size, high temperature capability (as compared to electronic sensors), the ability to isolate the sensor head from the electronic components by very large distances, and the ability to multiplex many thousands of sensors along a single fiber cable [2].

II. EXPERIMENTAL: In this work intensity modulated two-fiber probe for displacement measurement is developed using low cost plastic optical fibers. This type of sensor consists of a light source, transmitter fiber, reflector, receiving fiber and a photo detector. Micro displacement sensor based on arrangement such as shown in Figure1 are well studied [3,4,5]. The light from the light source enters the transmitting fiber and then radiates conically to the surface of the target. A part of the reflected light enters the receiving fiber and then is detected by the photo detector. The response curve for the micro displacement sensor shows three distinct regions -a blind region, linear region having positive slope and a nonlinear region having negative slope as shown in Figure 2. Sensor can be operated either in linear or no linear region depending up on application. It has been realized that instead of arranging the transmitting and receiving fibers parallel to each other, if they are inclined the sensitivity of the micro displacement sensor improves [5].

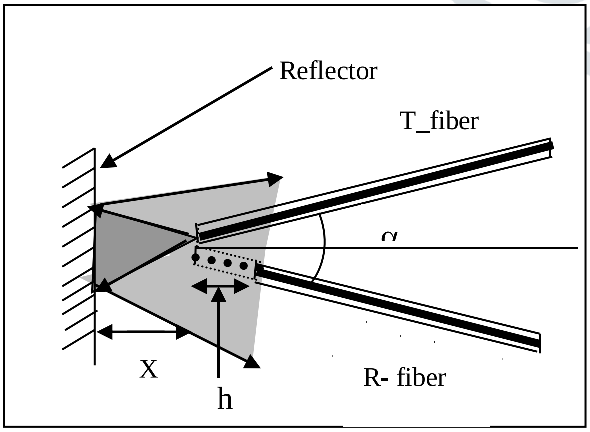

Figure1: Two fiber sensor structure

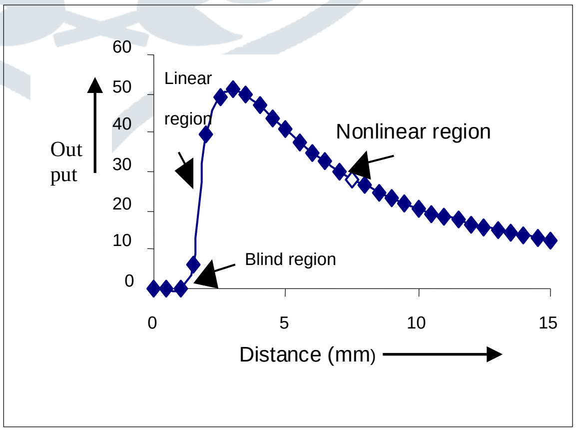

Figure 2: Response of displacement sensor

For the distance measurement various fiber optic based probe geometry has been reported [4]. For the typical two fiber, fiber optic intensity modulated displacement sensor the important parameters deciding the performance of sensors are the lateral separation between the transmitting and receiving fibers(s), the offset between transmitter and receiver tip (h), the core radius (a), and the numerical aperture (NA). The sensors performance and accuracy of measurement strongly depends on the geometry parameters of the probe. Especially the distance between sensing fiber tips and reflector, separation in transmitting and receiving fibers, offset in the fiber tips and angle of the reflector etc.

During the manufacturing of the sensor probe it is possible to have reflector not being perpendicular to the fiber end face as shown in figure 3. Thus this improper fiber face alignment causes variations in the performance of the sensor. As per the Taguchi method this is considered as one of noise factor for the designing of fiber sensor probe.

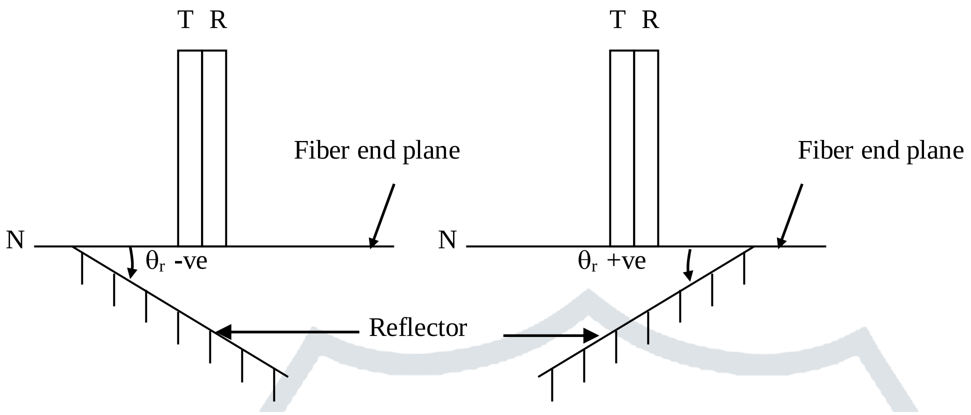

Figure 3 : Variable Angle of reflector (θ_r)

The variation in the range and sensitivity is due to geometrical consideration of the Transmitting (T) and Receiving (R) optical fiber [5]. The range and sensitivity mainly depends on the separation (s), the offset (h), the angle of inclination (α) and the angle of the reflector ($\pm\,\theta_r$) Thus factors such as s, h, & α are considered as controlling parameters with their 3 levels for the design of experiments using orthogonal array (OA) approach. However the angle of reflector θ_r is not controllable in this type of sensor. The θ_r may be positive or negative. The angle of reflector with normal of the fiber tip during the manufacturing is not easy to control and is therefore selected as a noise factor. There are 3 control factors with 3 levels and a noise factor with their 3 levels as shown in Table 1. Figure 4 shows the block diagram of experimental set up of FODS.

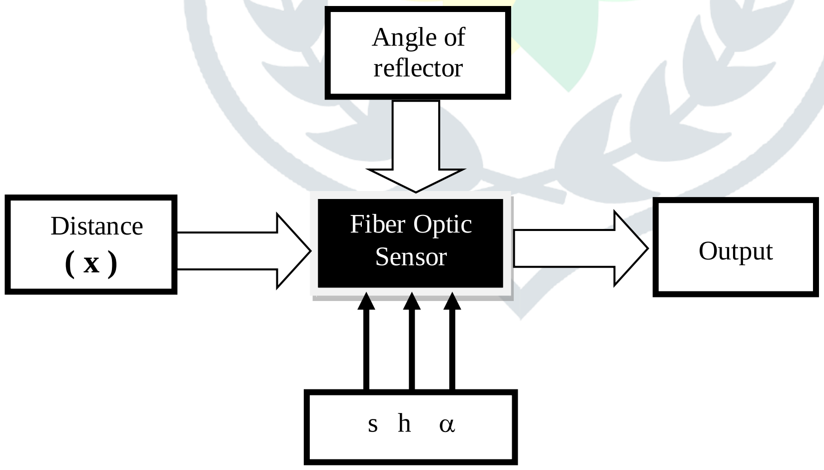

Figure 4: Block diagram of a FO Displacement **S**ensor

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Table 1: Control and Noise factors and their levels.

Control Factors		Level		
		1	**2**	**3**
A	Separation Distance (s) mm	0.0	0.5	1.0
B	Offset adjustment (h) mm	-0.5	0.0	0.5
C	Angle of inclination (α) degrees	0.0	5.0	10.0
Noise Factor				
Angle of Reflector (θ_r) degrees		-2	0	2

An L-9 array is chosen for designing the experimental layout based on the control factors and their corresponding levels, shown in Table 2. It comprises the simulated data for the sensitivity and range. Each row in this array is a separate experiment simulated to produces output response for the noise factor at their 3 levels. The out put performance that is output voltage of the FO displacement sensor is coded for each such nine experiments separately. The simulated data is then used to find out the statistical data analysis from L9 orthogonal array matrix and the factor assignments. The variance in the output signal is subjected to reduce in the form of mean.

The Larger the better signal-to- noise quality characteristics is used to find the effect of control parameters in the data analysis. It is the objective of the design activity to determine the best levels of these factors to achieve the FO displacement sensor (FODS) product/ process robustness. Here robustness refers to making the device insensitive to various sources of variation. Although control factors are studied to established their ideal values to accomplish the objective of the experiment, it would be useful to classify the effects of control factors on the quality characteristics or (response) as follows: Control factors affecting the mean quality of characteristics and noise factors or (response) only Control factors affecting the variability in response only; Control factors affecting the mean response and response variability; or Control factors affecting the neither the mean response and nor the response variability [6]. The choice of the right quality characteristics is essential for the success of any industrial experiments.

Table 2: OA L9 Experimental Layout and Output data

Exp No.	Column Numbers & Factor Assignment						
	1	**2**	**3**	Sensitivity		Range	
	A	**B**	**C**	Mean (Y)	S/N_{LB}	Mean (Y)	S/N_{LB}
1	1	1	1	07.36	15.67	02.00	05.45
2	1	2	2	13.33	21.68	01.83	05.01
3	1	3	3	21.47	26.91	01.50	02.48
4	2	1	2	6.52	15.99	01.83	05.01
5	2	2	3	11.46	21.45	01.66	04.20
6	2	3	1	03.45	08.99	02.00	05.45
7	3	1	3	06.91	16.98	01.83	04.56
8	3	2	1	01.98	04.15	02.16	05.93
9	3	3	2	03.73	11.35	02.16	05.71

III. DATA ANALYSIS: The signal to noise ratio (SNR) can be assumed as a response of the experiment, which is a measure of variation when uncontrolled noise factors are presented in the system. The maximum signal to noise ratio is advocated in Taguchi approach to maximize the performance of a system using control factors by minimizing the effect of noise variations using adjustable factors [7]. Figure 5 shows the various factor effects plots for the mean and S/N ratio for the FOD sensitivity analysis. On the similar line the Taguchi parameter approach is used to determine range analysis.

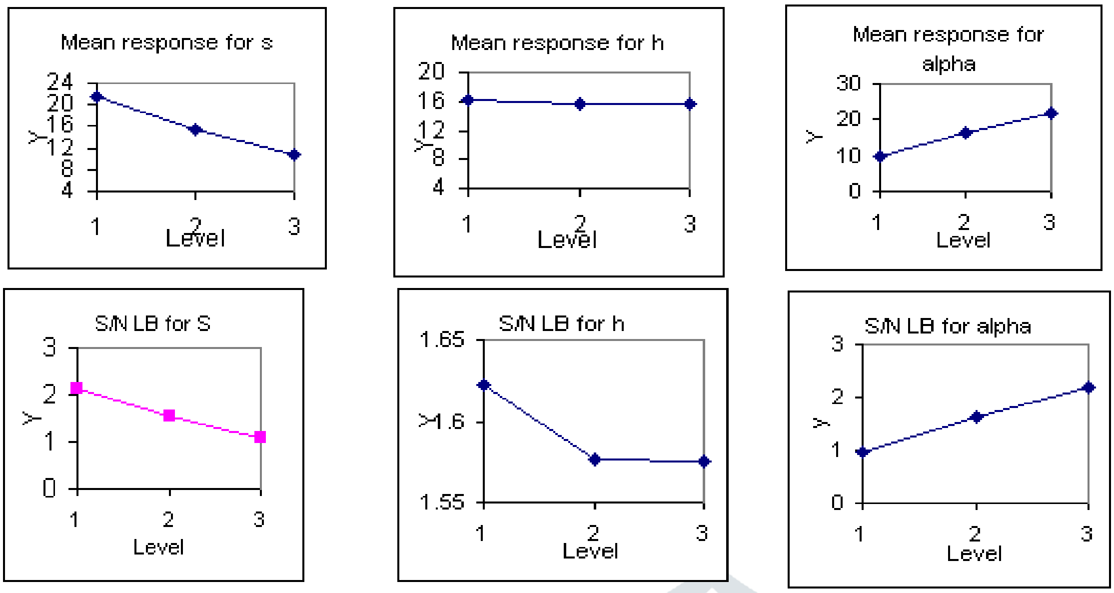

Figure 5: Factor Effect plots for sensitivity analysis

IV. RESULTS AND DISCUSSION: It reveals from figure 5 is that explores optimal parameter settings for FODS. The sensitivity performance is obtained for the robust parameter sensor design i.e. s1,h3,α3 and Mean s1,h1,α3 for S/N ratio. The optimum parameter settings obtained for the range is s3,h2,α1 and for the Mean s3,h2,α1 for S/N ratio. The optimal parameter setting has been achieved using Taguchi's orthogonal Array (OA) L9 parameter design approach. Thus we have optimized the FODS performance for the sensitivity and range analysis effectively. It is also observed from the above two figures that sensitivity remains constant in spite of variation in the angle of reflector. Hence the robust FODS sensor is designed successfully.

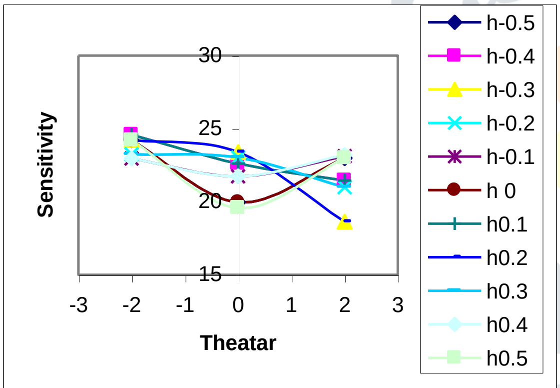

Fig.5: Effect of h on sensitivity

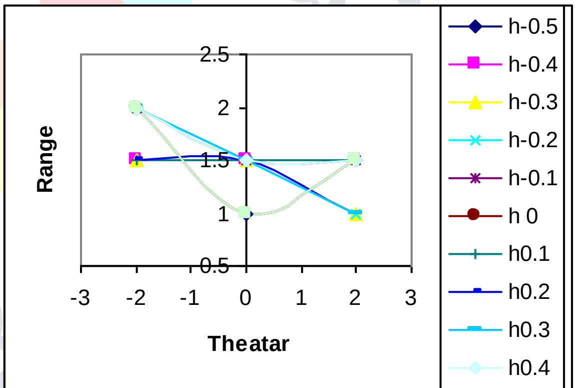

fig. 6:Effect of h on range

It is be noted that the sensitivity and range has less dependence on angle of inclination (α) and separation (s) however it is prone to sensitive to h value. The dependences is plotted for sensitivity in Figure 5. The dependence of range on h is shown in Figure 6. It suggests that the dependence of range on the angle of reflector for different h and it is seen that for the optimized values of h =-0.4 and h = 0.1 the range is constant. Thus it is advisable to keep either of this h value to keep sensor range independent of the reflector angle.

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