Use of Factorial Design for Temperature, Humidity, and Strain, for Characterization of FBGs

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Abstract

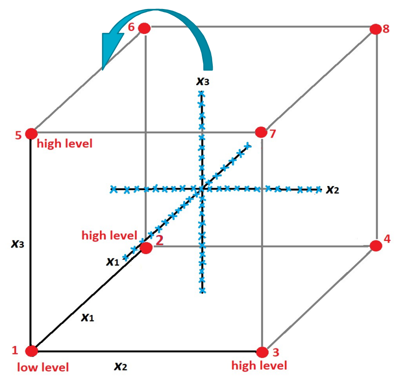
Factorial design can be used when treatments are combination of the levels of two or more factors that vary simultaneously. It provides the maximum amount of information with the minimum number of experiments. Factorial design allows estimation of sensitivity to each factor and also the effect of interaction between different factors. It is applicable in scientific and industrial researches. We report on the application of 3 variables 2 levels factorial design for simultaneous temperature, humidity, and strain sensing by using fiber Bragg gratings inscribed in standard optical fiber.

Factorial Design for 3 factors with two levels

- Use of Factorial Design to decrease the number of experiments in compare with Classical measurements
- *k factors and n levels for every factor: n^k measurement points*
- Data to be collected at the vertices of a hyper-cube in k –dimensions
- Cover all experimental domain

$$y = a_0 + a_t x_t + a_h x_h + a_s x_s + a_{th} x_t x_h + a_{ts} x_t x_s + a_{hs} x_h x_s + a_{ths} x_t x_h x_s$$

$$a = X^{-1}.y$$

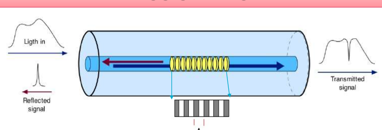


Trials	Temperature	Humidity	Strain
1	Low level	Low level	Low level
2	High level	Low level	Low level
3	Low level	High level	Low level
4	High level	High level	Low level
5	Low level	Low level	High level
6	High level	Low level	High level
7	Low level	High level	High level
8	High level	High level	High level

Trials	x_t	x_h	x_s
1	−1	−1	−1
2	+1	−1	−1
3	−1	+1	−1
4	+1	+1	−1
5	−1	−1	+1
6	+1	−1	+1
7	−1	+1	+1
8	+1	+1	+1

- Number of experiments: 2^3 all combination of levels for 3 factors
- 8 measurements: 8 equations; 8 unknowns
- Linear response of FBGs to the factors in the range of levels of factors in this experiment, ($y = \lambda_B$)

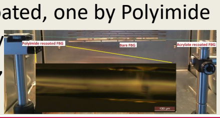
Fiber Bragg grating sensor



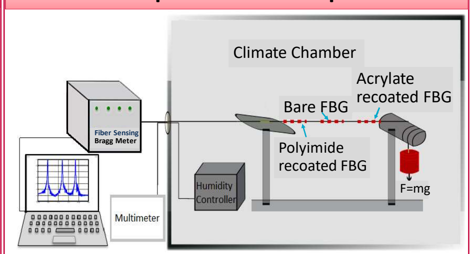
$$\lambda_B = 2\, n_{\text{eff}}\, \Lambda$$

$$\Delta\lambda_B = S_t \Delta T + S_\varepsilon \Delta S + S_h \Delta H$$

- Three uniform gratings, 4mm long, were inscribed in a standard optical fiber by a double frequency fiber laser emitting at 244 nm, by interferometric technique (Lloyd mirror set-up)
- Tow gratings were coated, one by Polyimide (PI2525), another one by Acrylate (DSM 950-200), third one remained bare



Experimental Set-up



Factor	Low level	High level
x_t (°C)	25	65
x_h (%rH)	30	70
x_s (με)	45.594	235.141

F= mg; weight of load

A: Fiber Cross section

E: Young modulus

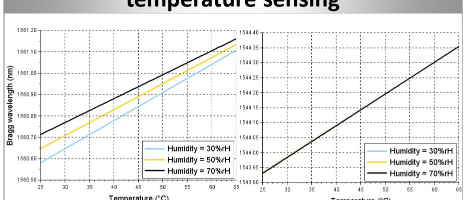
ε: Strain

$$\varepsilon = \frac{F}{A.E}$$

Results

Denormalized		Acrylate FBG	Bare FBG	Polyimide FBG
a'_0	(nm)	1526.274	1543.677	1560.115
a'_t	$(\frac{pm}{°C})$	10.69	10.37	14.63
a'_h	$(\frac{pm}{\%rH})$	−0.005	−0.17	4.54
a'_s	$(\frac{pm}{\mu\varepsilon})$	1.13	1.06	1.05
a'_{th}	$(\frac{pm}{°C\%rH})$	−0.002	0.003	−0.049
a'_{ts}	$(\frac{pm}{°C\mu\varepsilon})$	0.5×10^{-3}	2×10^{-3}	2×10^{-3}
a'_{hs}	$(\frac{pm}{\%rH\mu\varepsilon})$	-0.9×10^{-3}	1×10^{-3}	-0.9×10^{-3}
a'_{ths}	$(\frac{pm}{°C\,\%rH\mu\varepsilon})$	-1.64×10^{-5}	-6.59×10^{-5}	-1.64×10^{-5}

Effect of different levels of humidity on temperature sensing

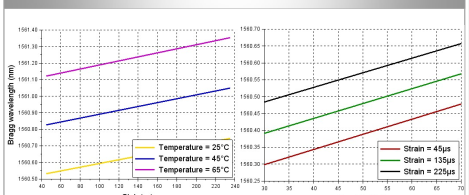


Polyimide recoated FBG

Bare FBG

Increasing humidity modifies temperature sensitivity for polyimide recoated FBG, while not effects on bare FBG.

Cross interaction between 2 by 2 factors



Polyimide recoated FBG

Modification of temperature not effects strain sensing, as well as for cross interaction between strain modification and humidity, in all gratings.

Conclusion

- In conclusion, factorial design is a powerful tool for FBGs characterization. In this study, we used factorial design to characterize FBGs cascaded in standard optical fiber Draka and obtain temperature, humidity, and strain sensitivities. In addition cross interaction coefficients between 2 by 2 and 3 by 3 factors were calculated.
- Temperature sensitivities of acrylate and bare FBGs are in agreement with classical measurements.
- Strain sensitivities of all FBGs are in good range.
- There is an increasing in temperature sensitivity due to polyimide coating.

References

1. K. O. Hill, B. Malo, F. Bilodeau, D. Johonson, and J. Albert, Bragg gratings fabricated in monomode photosensitive optical fiber by UV exposure through a phase mask, Applied Physics Letters, vol. 62, 1035-1037, 1993.
2. A. D. Kersey, M. A. Davis, H. J. Patrick, M. LeBlanc, K. Koo, C. Askin, M. Putnam, and E. J. Friebele, Fiber grating sensors, Journal of lightwave technology, vol. 15, 1442-1463, 1997.
3. D.R. Cox, N. Reid, The theory of the design of experiments, CRC Press, 2000.
4. G. E. P. Box, J. S. Hunter, and W. G. Hunter, Statistics for experimenters: design, innovation, and discovery, Wiley-Interscience, New York, 2, 2005.
5. L.Wang, N. Fang, and Z. Huang, High performance Polymers – Polyimides Based – From Chemistry to Applications, Polyimide- Coated fiber Bragg grating sensors for humidity measurements, InTech, ch. 8, 145-166, 2012.

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