Engineering of the fiber optic Bragg grating sensor of electrical parameters and software application for automatic simulation of its parameters

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Abstract

Nowadays one of the most effective transducer rised to the high demands based on metrological and exploitative characteristics are fiber optical. In the article there is modern state of measurement fiber optical sensors. Basic types and methods of measurement are examined. New model of fiber optic Bragg grating sensor for measurement of electric parameters is suggested. For the suggested model a program for computing the parameters of sensor is written, valid model is presented on experimental board. The results of the work and their valuating are received.

Keywords: fiber Bragg grating; fiber optic sensor; multisensor networks; direct current; commuted current; electrostatic field; magnetic field

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1. Introduction

Nowadays one of the most effective transducer rised to the high demands based on metrological and exploitative characteristics are fiber optical, optomechanical, optoelectronic, transducer of the physical values with information transmission from sensor to controller by the fiber optic interconnections (with built-in fiber optic interconnections FOI).

Until quite recently the main type of sensor for measurement of mechanical deformation and temperature were strain gage sensors, piezotransducers, thermo-resistors and others. However thank for intensive development of fiber optics fiber optic sensors were elaborated and receives grate expansion possessing some advantages comparing to strain gage sensors: they possess higher sensitivity, interference protection, immunity to the influence of aggressive environments and lower cost.

Among fiber optic sensors the most perspective are quasi-distributed fiber optic Bragg grating sensor (further FOBGS), afforded to control the state of the object in most points at the same time due to the possibility of spectral and time multiplexing.

2. Development of the mathematical model

Bragg gratings bunch the main mode of fiber optic guide emitted in the straight direction in fiber optic guide with the main mode emitted in the opposite direction on the resonant wavelength λ_{Br} determined by the correlation [2]:

$$\lambda_{Br} = 2n_{eff}\Lambda,$$

where n_{eff} is efficient reflection index core of fiber of the main mode, Λ period of Bragg grating.

Spectral properties are the most important characteristics of Bragg gratings. The main of them are spectral location resonance its width and reflect coefficient at a maximum. Calculation of spectral characteristics of Bragg gratings usually accomplish with the use of mode coupling theory. Let's express the coefficient function of Bragg grating from wavelength by the mode coupling theory [3]:

$$r = \frac{sh^2(\gamma_B L)}{ch^2(\gamma_B L) - \frac{\sigma^2}{\kappa^2}},$$

where $\gamma_B \equiv \sqrt{\kappa^2 - \sigma^2}$ is spectral offset from strict resonance σ determines by the difference of propagation constants of the main mode $\beta = \frac{2\pi n_{eff}}{\lambda}$:

$$\sigma(z) = \beta(z) - \beta_{Br}(z) = \frac{2\pi n_{eff}(z)}{\lambda} - \frac{\pi}{\Lambda(z)},$$

where local reflection effective value is $n_{eff}(z) = n_{eff} + +\eta \cdot \Delta n_{\mathrm{avr}}(\mathrm{z})$

Coherence coefficient of grating $\kappa(z)$ on the wave length λ is proportional to the mod modulating range induced reflection value $\Delta n_{mod}(\mathrm{z})$:

$$\kappa(z) = \frac{\pi\eta\Delta n_{mod}(z)}{\lambda}$$

$\eta -$ quantity of main mode power that propagates in the optic guide core.

Resonance spectral width on the half-height Bragg gratings might be expressing the following close correlation [3]:

$$\Delta\lambda_{0,5} = 2\lambda\alpha\sqrt{\left(\frac{\eta\Delta n}{2n_{eff}}\right)^2 + \left(\frac{\Lambda}{L}\right)^2}$$

where α is about 1 for the deep grating (with reflection value $r \sim 1$) and is about 0.5 for the small depth gratings.

For the grating with modulation period $\Lambda = 67{,}06\mu m$ and with the refraction deviation index $\Delta n = 10^{-4}$ spectrum of reflection of light signal will look as on the fig.1:

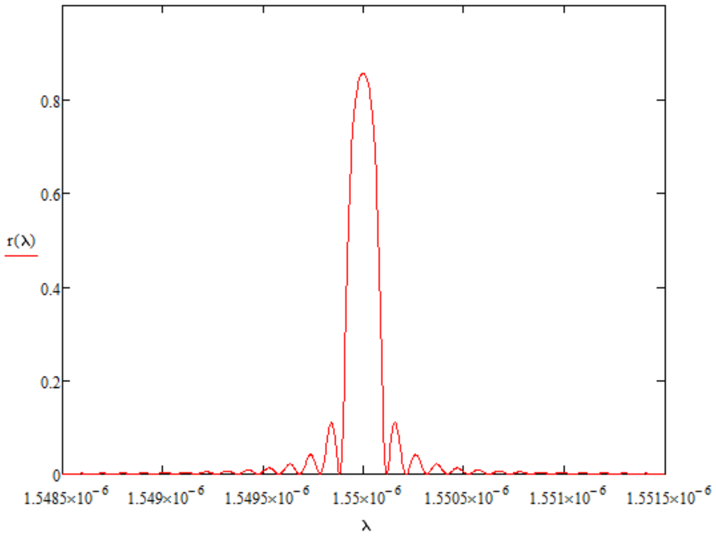


Fig. 1. Spectrum of the reflected signal.

Central wavelength of optic emission reflected by the Bragg grating depends on the effective refraction value and on the grating period. Changing of the central wavelength taking in account the influence of the temperature and mechanic strain determines this way [4]:

$$\Delta\lambda_B = 2\left(\Lambda\frac{\partial n_{eff}}{\partial l} + n_{eff}\frac{\partial \Lambda}{\partial l}\right) + 2\left(\Lambda\frac{\partial n_{eff}}{\partial T} + n_{eff}\frac{\partial \Lambda}{\partial T}\right),$$

where n_{eff} – is efficient reflection index core of fiber of the main mode, Λ period of Bragg grating.

The first component in this formula gives the value of wavelength shift depending on deformation (elongation). The second depending on the temperature. The dependence of the shift of the central wavelength of the reflected emission from the deformation also may be showed in the following way:

$$\Delta\lambda_B = \lambda_B(1 - p_e)\delta_Z,$$

where p_e is a constant of deformation optic fiber is calculated from the following formula:

$$p_e = \frac{n_{eff}^2}{2}\left(p_{12} - v(p_{11} + p_{12})\right),$$

where p_{11} and p_{12} Pockels coefficients in the tensor optical strains, v Poisson ratio. For the typical fiber $p_{11} = 0{,}113$, $p_{12} = 0{,}252$, $v = 0{,}16$ and $n_{eff} = 1{,}4447$. On the bases of values of sensitivity for the wavelength $\lambda_B = 1550\ nm$ will make $12{,}36 nm/\%$.

By the stretching optic fiber the length of Bragg grating changes, the period of the modulation of the refraction index and there is the change of refraction indexes of core and cover of optic fiber. Formula for changing of efficient reflection index as result of stretching is designated by photoelastic effect so that

$$\Delta n_\delta = -\frac{1}{2}n_{eff}^3 \cdot p_e \cdot \delta_Z$$

it is related to anisotropy of optic fiber occurring by stretching.

The second element gives the dependence of wavelength shift from temperature. Emission wavelength reflected from Bragg grating sensors changes in dependence from temperature because of the following factors: heat expansion of optic fiber (stretches out period of Bragg grating) in other words there is a changing of grating mechanical length moreover there is a changing value of fiber refraction depending on temperature (changing of grating optical length). Whence it follows that the dependence of wavelength shift on temperature can be described the following formula [4]:

$$\Delta\lambda_B = \lambda_B(\alpha_\Lambda + \alpha_n)\Delta T,$$

where α_Λ is temperature coefficient of linear expansion ($\alpha_\Lambda = 0{,}55 \cdot 10^{-6}$ is for fused quartz), α_n thermo-optic coefficient ($\alpha_n = 8{,}6 \cdot 10^{-6}$ is for optic fiber with doped germanium). Due to these values of sensitivity of Bragg grating to the temperature for the wavelength $\lambda_B = 1550\ nm$ will be $14{,}1\frac{pm}{°\mathrm{C}}$.

The diagrams of wavelength dependence form the deformation and temperature are presented on fig. 2. The diagram of dependence from deformation is presented on the top; the diagram of dependence from temperature is below.

3. The software for simulation technical parameters

For the simulation of work of this type of sensors automation system was developed.

The window of this system is presented on the fig. 3. The user has various opportunities for editing parameters of simulation. After pressing the button «Добавить график» in the both diagrams new simulated data is appearing which are different from the previous by color. Therefore user has an opportunity of clearing the diagrams, all the fields and report generation according to data by pressing the button «Report».

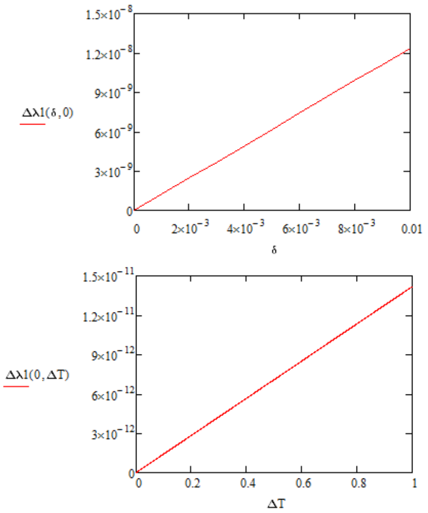
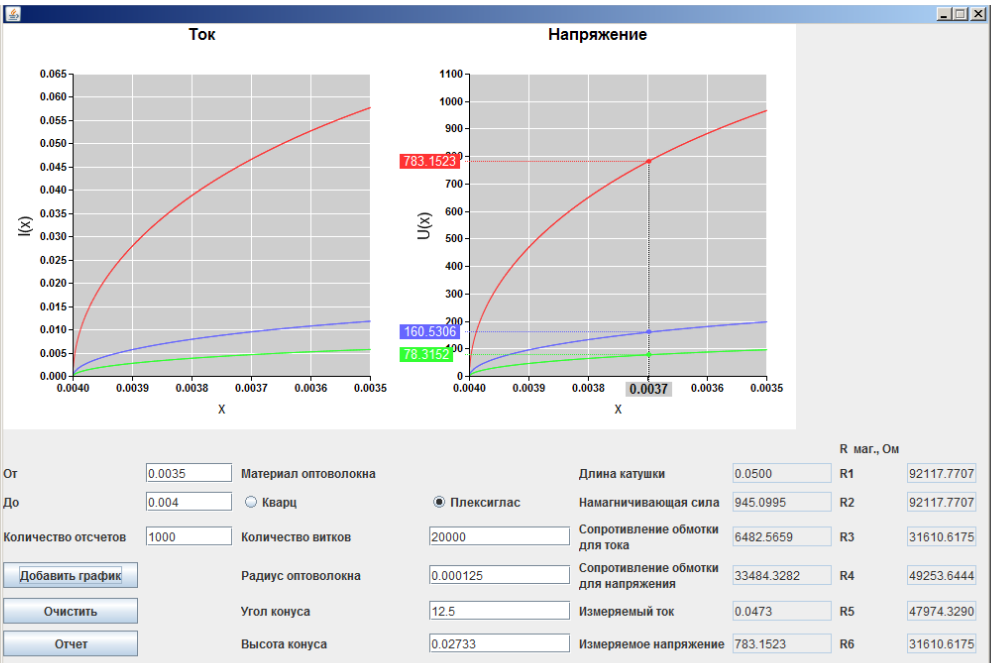


Fig. 2. The diagrams of wavelength dependence form the deformation and temperature.



R маг., Ом

От 0.0035

До 0.004

Количество отсчетов 1000

Материал оптоволокна

○ Кварц ● Плексиглас

Количество витков 20000

Радиус оптоволокна 0.000125

Угол конуса 12.5

Высота конуса 0.02733

Длина катушки 0.0500

Намагничивающая сила 945.0995

Сопротивление обмотки для тока 6482.5659

Сопротивление обмотки для напряжения 33484.3282

Измеряемый ток 0.0473

Измеряемое напряжение 783.1523

R1 92117.7707

R2 92117.7707

R3 31610.6175

R4 49253.6444

R5 47974.3290

R6 31610.6175

Fig. 3. Software interface.

4. Laboratory tests

In the course of the works on optic fiber sensor of electrical parameters suggested mathematical model was taken. Further on the bases of this model the sensor design was developed for laboratory tests and exposure of efficiency of its work. On the fig. 4 principle diagram of sensor organization is presented.

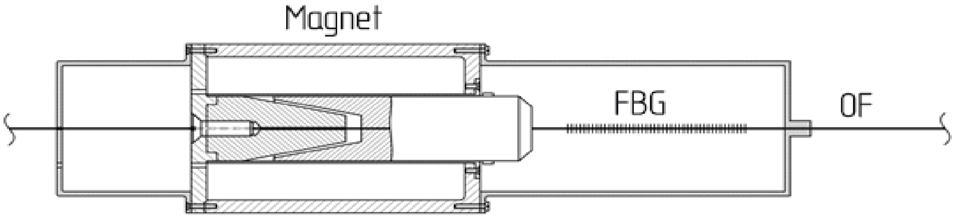


Fig. 4. Sensor organization.

In the course of the laboratory tests the experiments on the stand were performed where the sensor was assembled and the results of minimal sensitivity were received and the critical parameters of this sensor were committed (fig. 5, 6). Data received after performance of tests of this stand. Parameters of power supply: 20V, 2.5A. On the diagram we can see the surge of wavelength changing reflecting specter from intrafibrous Bragg grating during the admission of power supply on the coil (number 7 on the fig. 5) (1524.990 – 1525.048nm).

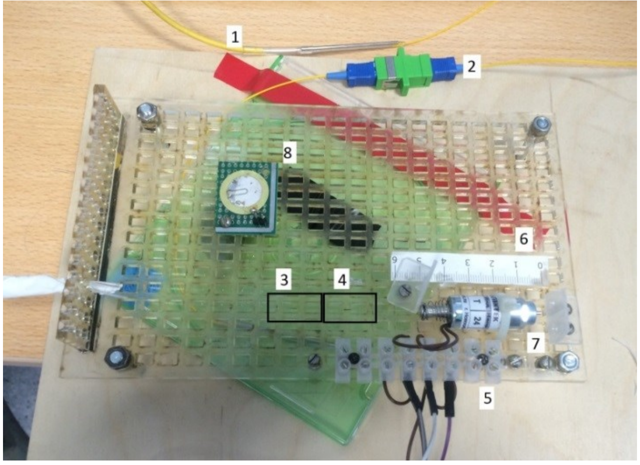


Fig. 5. The stand photo (1 optical fiber, 2 connector, 3,4 Bragg gratings, 5 electrical connectors, 6 ruller, 7 coil, 8 pueso element(is not used)).

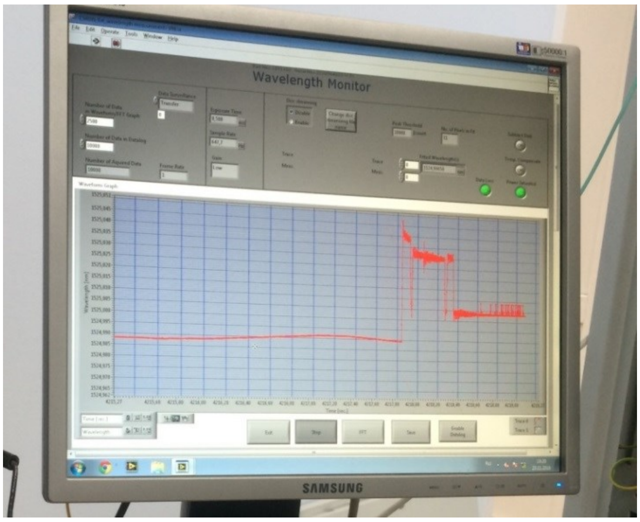


Fig. 6. Interrogator software photo.

5. Conclusion

During the analysis of analogs optical fiber current sensors the problems were educed: sensitivity to EM fields, amplitude separation of channels, sensitivity to acoustical influences, low correlation signal/noise. This device is suggested as a prototype which consists optical fiber with Bragg grating as a sensitive element, electromagnet for transformation electric energy into mechanic energy, optical fiber as a transfer channel and spectral analyzer with digital output for connecting to the PC. This device is free from the previously described problems. The laboratory test showed that resolution capability and sensitivity has quite high values and let use this types of sensors in the various measurement range of parameters.

References

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