Design of a Graphical User Interface for Analysis of a Fiber Optic Current Sensor

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Abstract

In this study, a graphical user interface has been developed for a fiber optic current sensor model. As input, users enter values of laser current and wavelength, number of turns of the fiber optic and current flow through a conductor. At the end of the numerical analysis of the model, this interface can calculate values of the laser output power, refractive index, Verdet constant and attenuation of the fiber optic and measured current. Thus, it is possible to examine the effects of wavelength on many parameters, easily.

1. Introduction

Fiber optic (FO) technology has led to improvements of networks, navigation, avionic and sensor applications [1]. FO sensors, have played important role since 1970s, worked out unique solutions in area of industry, engineering and scientific researches [2]. Optical voltage and current sensors which are used to measure high voltages and/or high currents have important advantages such as high accuracy, less weight and have not a saturation problem [3]. FO current sensors have immunity from high voltages, electromagnetic interference and have high bandwidth and compact sizes [4,5].

Rahmatian and Blake [3] measured currents from 2 A to 3600 A using FO current sensor in accuracy of 0.1% in their study. Li et al. [6] developed an optical alternate current sensor in range of 2-50 kA in resolution of 0.1 A in a study. In a study, bus-bar current was measured using FO current sensor [7], in another study a portable FO current sensor were developed for monitoring power systems [5]. By Aydogan and Aras [8], components of a FO current sensor system were modeled and simulated in environment of the Matlab Simulink. Faraday based FO current sensors utilize of the phenomenon that is, magnetic field induced by electric current changes rotation angle of the polarized light [4,9]. By Dai et al [10], a sensor head structures which detects Faraday rotation were simulated and it was seen that solenoid design structure has been implemented easier.

In this study a graphical user interface (GUI) has been developed for Faraday based FO current sensor system. This GUI helps to investigate relationship among laser output power, Verdet constant, refraction index and attenuation values of the FO and laser current, laser wavelength, the number of turns of FO and current flowing through a conductor. The second, third and fourth sections have been addressed to the mathematical background, the GUI design and conclusion respectively.

2. The Mathematical Background

Output power of a semiconductor laser diode that depends on wavelength and laser electric current is subject to some differential equation [11,12]:

$$P(t) = \frac{V_a \eta h v}{2\Gamma \tau_p} S(t) \tag{1}$$

where $S(t)$ denotes photon density, Γ denotes optical confinement factor, V_a denotes volume of the active region, η denotes total quantum efficiency, h denotes Plank's constant, v denotes the laser frequency and τ_p denotes photon lifetime.

$$\frac{dS(t)}{dt} = \Gamma g_0 \frac{\left[N(t) - N_o\right] S(t)}{1 - \varepsilon S(t)} - \frac{S(t)}{\tau_p} + \frac{\Gamma \beta}{\tau_n} N(t) \tag{2}$$

where g_o is slope gain, N_o is carrier density at transparency, $N(t)$ is carrier density, β is spontaneous emission factor, ε is gain saturation parameter and τ_n is carrier lifetime.

$$\frac{dN(t)}{dt} = \frac{i(t)}{qV_a} - g_0 \frac{\left[N(t) - N_o\right] S(t)}{1 - \varepsilon S(t)} - \frac{N(t)}{\tau_n} \tag{3}$$

where $i(t)$ is the laser current.

An equation obtained from experimental data has been conducted to investigate relationship between refractive index of a silica glass and laser wavelength for the range of 0.21 µm – 3.71 µm at 20°C as in [13]:

$$n_\lambda = 1 + \frac{0.6961663\lambda^2}{\lambda^2 - (0.0684043)^2} + \frac{0.4079426\lambda^2}{\lambda^2 - (0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2 - (9.896161)^2} \tag{4}$$

According to [14], Verdet constant of the FO is proportional to $(n^2-1)^2/(n\lambda^2)$. The relationship between Attenuation coefficient of the FO and wavelength is given in equation (5) as in [15]:

$$\alpha(\lambda) = 7.81 \cdot 10^{11} e^{-\left(\frac{48.48}{\lambda}\right)} + \frac{1}{\lambda^4} \quad (5)$$

Wollaston prism [10] has been used as the analyzer which split incident light from the FO into between horizontal and vertical component. The split lights have induced to two currents by two photodiodes. The signal processing (SP) unit has been calculate the current flowing through conductor by means of equation (6) as in [16]:

$$I = \frac{1}{2VN} \arcsin\left(\frac{I_y - I_x}{I_y + I_x}\right) \quad (6)$$

where V denotes Verdet constant and N denotes the number of turns of FO cable, I denotes the measured current $I_{x,y}$ denotes the photodiodes currents induced by light of the horizontal and vertical components.

3. Design of the GUI

In this study a GUI involving a fiber optic current sensor model using Matlab software. The operation process of this sensor can be summarized that light, produced by laser is linearly polarized by a polarizer, is transmitted into a FO which winds N turns around a conductor. Angle of the linearly polarized light in FO is changed by the conductor current due to the fact that Faraday effect. Then the light leaves the FO and splits into horizontal and vertical components by the analyzer. Two photodiodes convert these lights into the electric current signals. A signal processing unit conducts to calculate the conductor current using these photodiodes currents [8].

Using the designed GUI, users enter values of laser current and wavelength, number of turns of the fiber optic and current flow through a conductor and press “Calculate” button to start numerical analysis as seen in Figure 1.

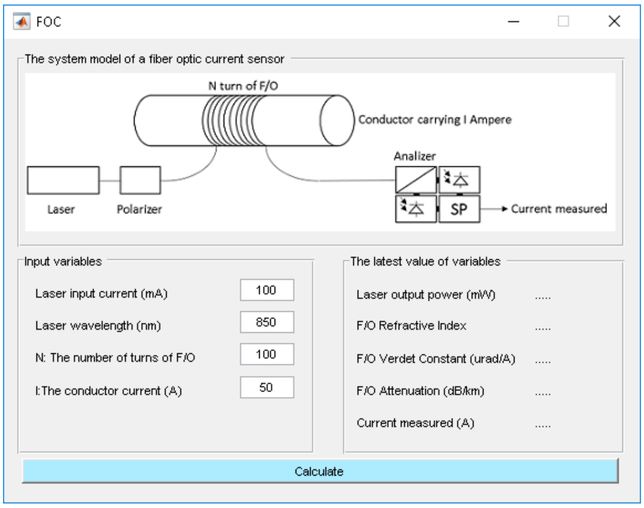

Fig. 1. The design of GUI

Output power of the laser, refractive index, Verdet constant and attenuation values of the FO and the measured current are represented in the GUI at the end of 10 ms of the numerical analysis as seen in Figure 2.

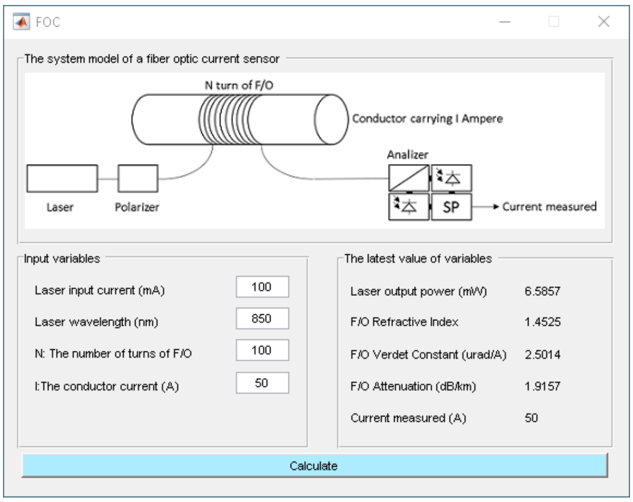

Fig. 2. Results of the numerical analysis

The laser output power was calculated as6.5857 mW, the refractive index as 1.4525, the Verdet constant as 2.5014 µrad/A, the attenuation as 1.9157 dB/km and the measured current 50 A when laser input current was 100 mA, the laser wavelength was 850 nm, the number of turns of FO is 100 and the conductor current is 50 A. Users can specify a range of the wavelength in the analysis as seen in Figure 3.

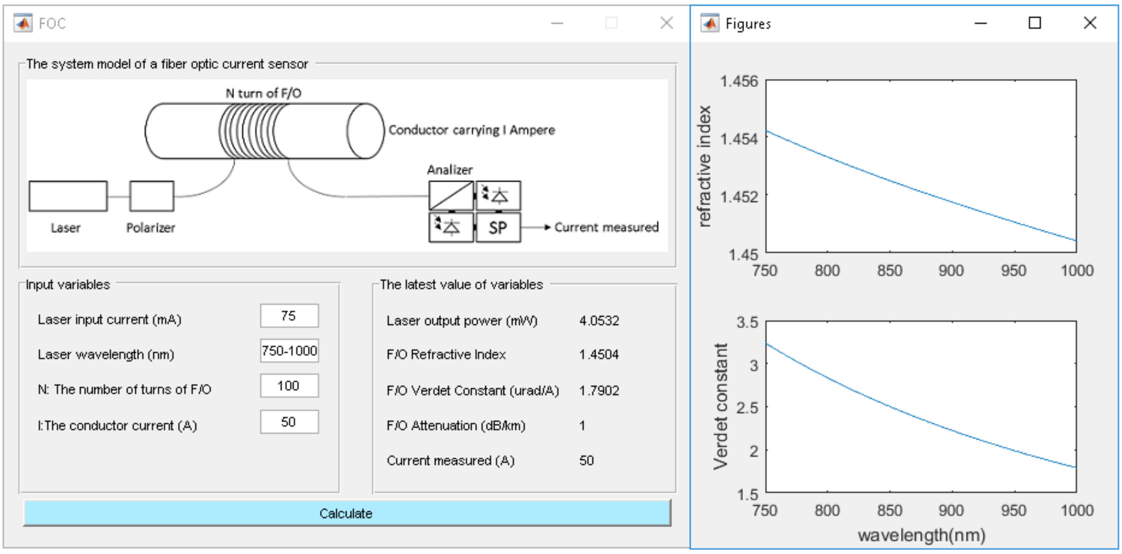

Fig. 3. Results of the ranged analysis

In the Figure 3, a user investigated that the laser output power was calculated as 4.0532 mW, the refractive index as 1.4504, the Verdet constant as 1.7902 µrad/A, the attenuation as 1 dB/km and the measured current 50 A when laser input current was 75 mA, the laser wavelength was 1000 nm, the number of turns of FO is 100 and the conductor current is 50 A. Furthermore, the refractive index and the Verdet constant versus the wavelength ranged between 750 nm – 1000 nm were plotted as seen in Figure 3.

4. Conclusions

A Matlab GUI has been designed for numerical analysis of a Faraday based FO current sensor system model. As input, users enter values of laser current and wavelength, number of turns of the fiber optic and current flow through a conductor. At the end of the numerical analysis of the model, this interface can calculate values of the laser output power, refractive index, Verdet constant and attenuation of the fiber optic and measured current.

For future studies, the GUI can be enhanced by adding the all inputs as ranged and output values can be plotted versus selected inputs. Also the GUI can be developed and released as a standalone application.

5. References

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