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Dedicated to Professor Jan Dorosz
on the occasion of his 65th birthday

Magnetooptic effect of photonic crystal fiber in blue region of visible spectrum

K. BARCZAK*

Department of Optoelectronics, Faculty of Electrical Engineering at the Silesian University of Technology,
2 Krzywoustego St., 44-100 Gliwice, Poland

Abstract. The phenomenon of optical birefringence in optical fibers is caused by external factors and stress induced by the manufacturing process. This optical birefringence makes it difficult to apply optical fibers as a polarimetric sensors head. Author of this paper, proposes the application of index guiding photonic crystal fibers because stress values in a fiber core caused by internal and external factors are lower. In this paper investigation results extended in comparison with the previous author's investigations are presented. This extension relies on investigation of magnetooptic for wavelength 405 nm. On the basis of experimental results optimal work points of optical sensing fibers were determined.

Key words: magnetooptic effect, optical fiber current sensors, photonic crystal fiber.

1. Introduction

Elastooptic effects in optical waveguides which are caused by external factors are one of the major problems of optical fiber current sensors basing on the Faraday effect [1–4]. The most important unwanted factors are: bending, compressing, expanding and twisting. Internal stress induced in manufacturing process is next undesirable factor [5–7]. It should be emphasized that, enumerated above, external factors along with temperature may result in changes of stress distribution. Recapitulating: all these features contribute to instability of a state of polarization (SOP) at the end of an optical fiber. In order to eliminate this unwanted effect one can apply optical fibers of very high [8–10] or very low birefringence [1, 11]. This paper is focused on possibility of application of index-guiding photonic crystal fibers (IGPCF) [12]. These fibers are characterized by following features [13]:

- broad spectrum of single-mode operation regime,
- low attenuation (if they are made of silica glass),
- compatibility with existing fiber connector types and technology of silica fiber splicing.

Additionally, in the article [14] it was pointed out that "orifices in the cladding may improve the stability of the state of polarization of the light. The perforated cladding of waveguide can reduce the effect of stresses in the external layer of the fiber on the deformation of the core". The results presented in this article confirm this thesis. For this reason the investigations described in [14] were repeated for a shorter wavelength. It is well known [15] that the Verdet constant is higher for shorter wavelengths. It also appears that for these wavelengths commercially available single-modal silica fibers have different material properties and different refractive index profile because of cut-off wavelength. As a result they do not show suitably higher magnetooptic sensitivity. Commercially available single-modal optical fibers show very small magnetooptic sensitivity for $\lambda = 405$ nm as is shown in Figs. 7 and 11).

Issues elaborated above allowed for the following thesis: In optical fiber a current sensors area, the IGPCF have better properties than standard step-index fibers for wavelength near 400nm. IGPCFs have higher magnetooptic sensitivities and higher resistance to external forces, especially produced by deformation.

2. Experimental part

In order to prove the thesis given in this paper, some comparison tests were planned. Two types of optical fibers were chosen: a step-index optical fiber and the IGPCF. Both fibers were investigated for two wavelengths $\lambda = 405$ nm and 635 nm. Preformed measurements allowed to determine a sensitivity to magnetooptic effect in disturbed (with strong mechanical vibrations) and undisturbed conditions (without vibrations).

Table 1
Description of optical fibers tested toward sensitivity to magnetooptic effect

	for wavelength 635 nm		for wavelength 405 nm	
	without vibration	with vibration	without vibration	with vibration
step-index	name: SM635 cladding: 125 mm length: 205 cm		name: SM405 cladding: 125 mm length: 205 cm	
index guiding photonic crystal fiber	name: IGPCF cladding: 125 mm length: 205 cm			

In the paper different step-index fibers have been used for different wavelength because of single-modal operating regime. The fibers were tested on the measuring setup presented in [14]. The setup was expanded of laser operating

*e-mail: kbarczak@polsl.pl

at $\lambda = 405$ nm. The testing process was carried on for DC magnetic filed in range from 0 to 27 mT. Additionally, the measurements were carried out, for a different state of polarization (SOP) azimuth at the input of tested fibers. The SOP azimuth varied in a range from 0 to 180 degree with step equal to 1 degree. The purpose of this effort was determination of a relationship between the input and output azimuth of SOP. It allowed to detect a presence of linear birefringence and its variations (fluctuations).

Moreover, long term investigations of SOP stability were performed in order to determine fluctuations of magnetooptic sensitivity of tested fibers. These measurements were carried out for a single angle of SOP azimuth, for varying induction of DC magnetic field in a range from 0 to 27 mT. Every measurement lasted 16 s. Subsequent measurements were registered in 16 s intervals.

Measurements carried out in function of input SOP azimuth are burdened with high uncertainty because the laser was pigtailed with step-index fiber which was unable to maintain a SOP. The situation looks much better for long term measurements because a section of the fiber pigtailed to the laser was not twisted in order to set desired values of SOP azimuth.

3. Results and discussion

In this paragraph results of measurements which allowed to determine sensitivity to magnetooptic effect for both types of tested optical fibers are presented. For the sake of simplicity, an input SOP azimuth resolution and a time resolution was diminished.

Comparing dependencies of sensitivity to magnetooptic effects in function of the input SOP azimuth for $\lambda = 650$ nm, one can see that the step-index fiber shows much smaller SOP stability in comparison with IGPCF (Fig. 1). The characteristics presented in Fig. 1 show that the step-index fibre is birefringent which manifests in high changes of the input SOP azimuth for $\alpha = 5°$. The remaining characteristics, presented in Figs. 2–4 show that there is no advantage of the IGPCF over the step-index fibre.

The long term stability measurements for wavelength $\lambda = 650$ nm presented in Figs. 5 and 6 clearly show that in the presence of mechanical disturbances, the IGPCF fiber is much more stable. Presented results indicate that deformation of the IGPCF fibers induces smaller elastooptic birefringence in their cores than in the step-index fibers.

In Fig. 9 an anomaly in the form of interference for angles greater than 110 deg can be observed. This is due to accidental deformation of the supplying fiber, which is not polarization-maintaining.

The results for $\lambda = 405$ nm are much more interesting (Figs. 7–12). In this case a characteristics of magnetooptic sensitivity in function of the input SOP azimuth (Figs. 7–10) as well as long term stability characteristics (Fig. 11 and Fig. 12) clearly support the thesis given in this paper. The sensitivity of the IGPCF is considerably higher than for the step-index fiber. Either long term characteristics show much better stability in case of the IGPCF. In particular it should be emphasized that magnetooptic sensitivity of the IGPCF is considerably higher for $\lambda = 405$ nm than for $\lambda = 650$ nm and that sensitivity is less dependent on the input SOP azimuth in case of measurements carried out with external disturbances.

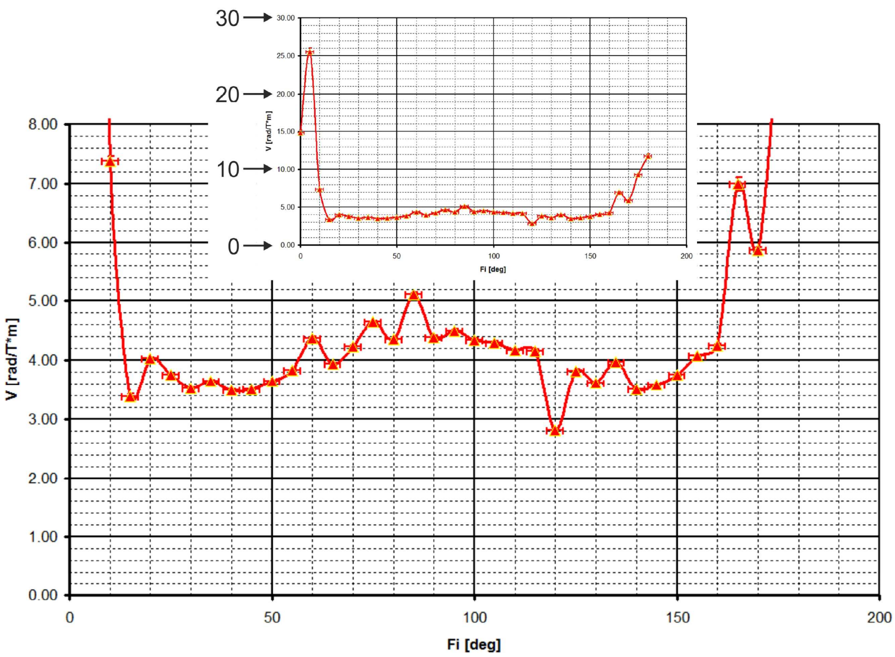

Fig. 1. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: step-index; wavelength: 635 nm; external disturbation: no

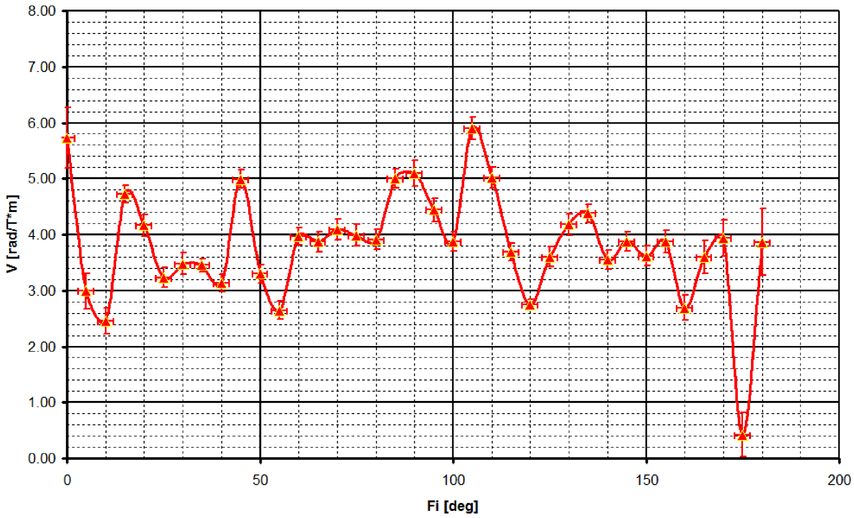

Fig. 2. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: step-index; wavelength: 635 nm; external disturbation: yes

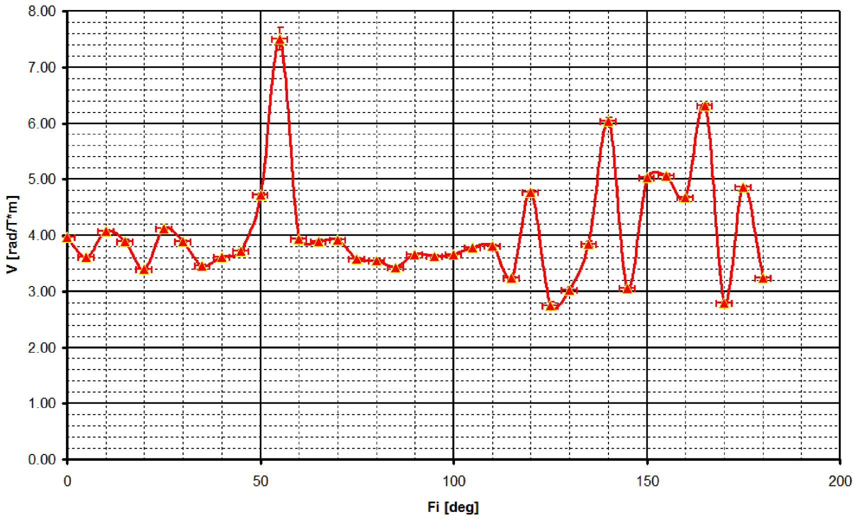

Fig. 3. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: IGPCF; wavelength: 635 nm; external disturbation: no

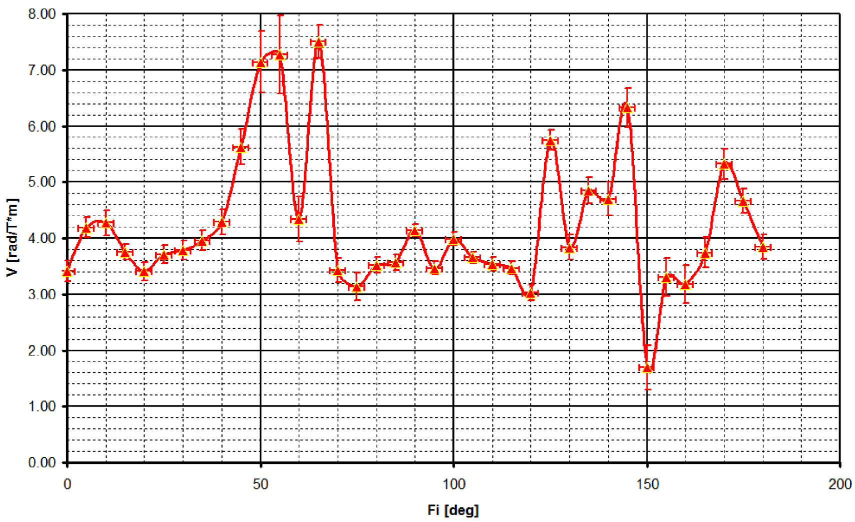

Fig. 4. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: IGPCF; wavelength: 635 nm; external disturbation: yes

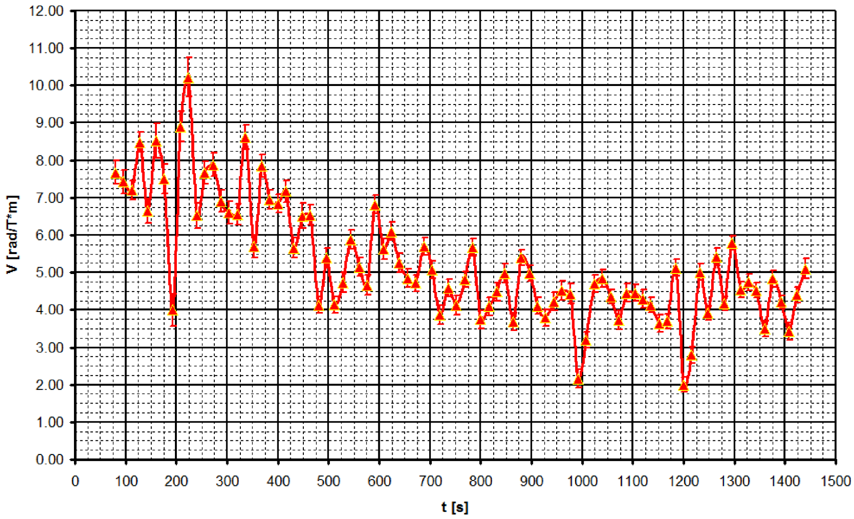

Fig. 5. Time series of magnetooptic sensitivity V measurements. Fiber: step-index; wavelength: 635 nm; external disturbation: yes

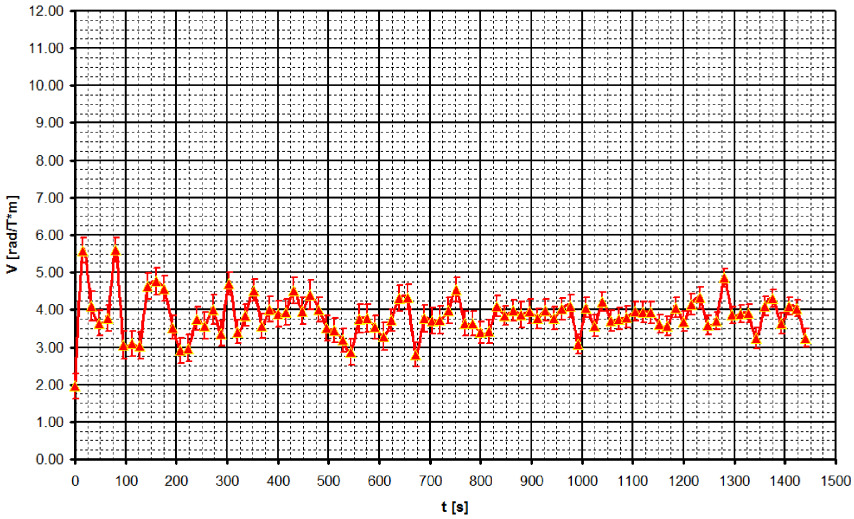

Fig. 6. Time series of magnetooptic sensitivity V measurements. Fiber: IGPCF; wavelength: 635 nm; external disturbation: yes

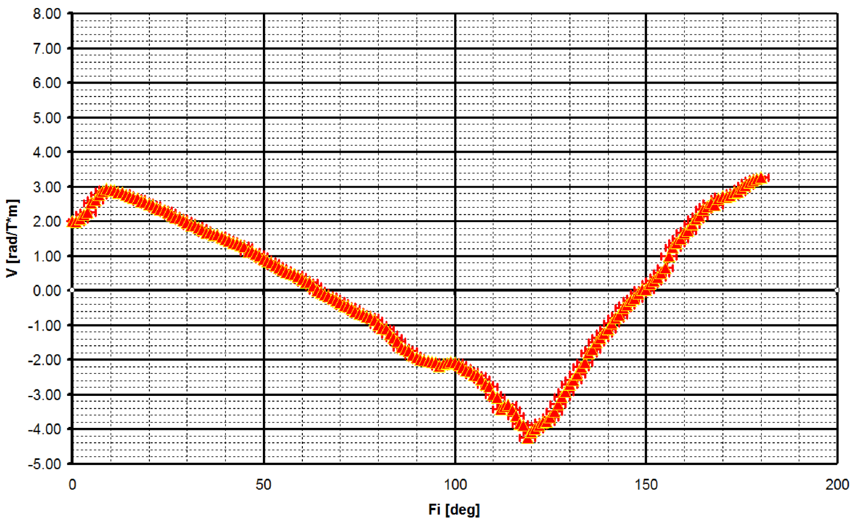

Fig. 7. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: step-index; wavelength: 405 nm; external disturbation: no

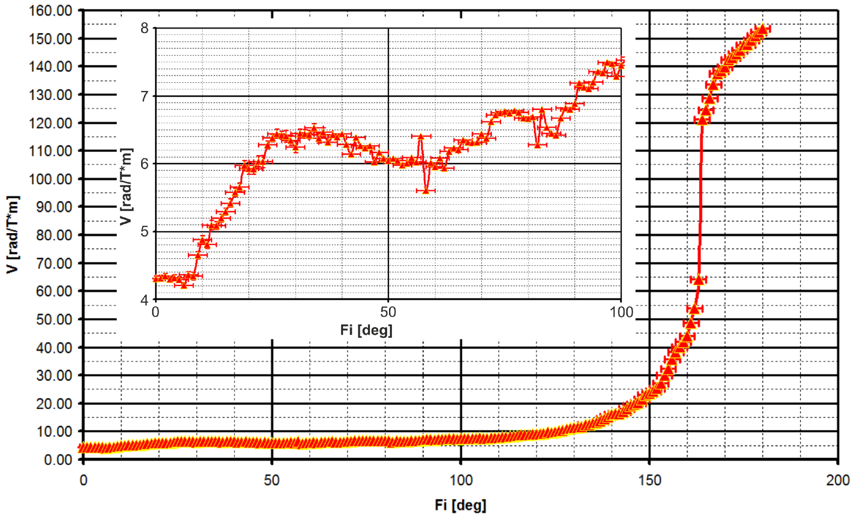

Fig. 8. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: step-index; wavelength: 405 nm; external disturbation: yes

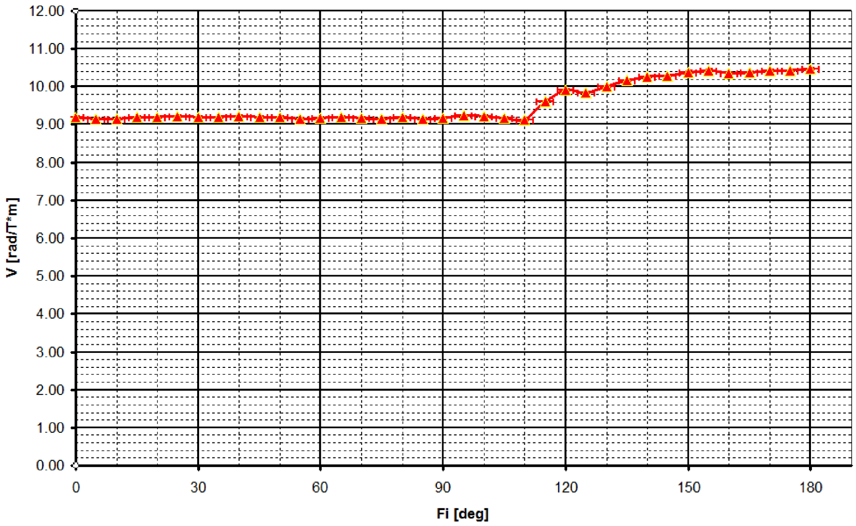

Fig. 9. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: IGPCF; wavelength: 405 nm; external disturbation: no

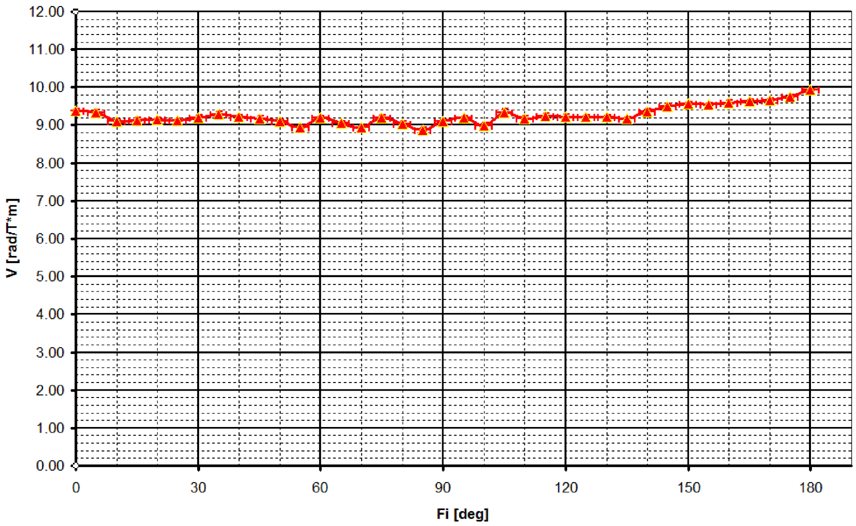

Fig. 10. Characteristic of magnetooptic sensitivity V as a function of the input SOP azimuth. Fiber: IGPCF; wavelength: 405nm; external disturbation: yes

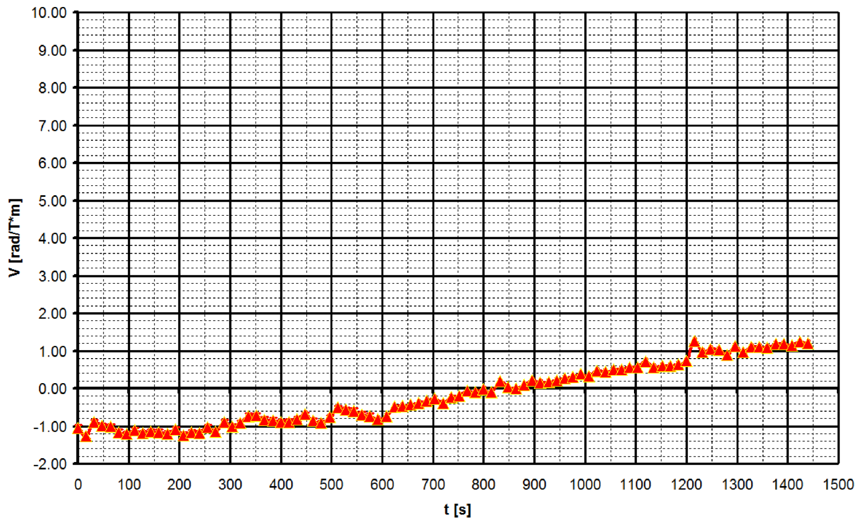

Fig. 11. Time series of magnetooptic sensitivity V measurements. Fiber: step-index; wavelength: 405 nm; external disturbation: yes

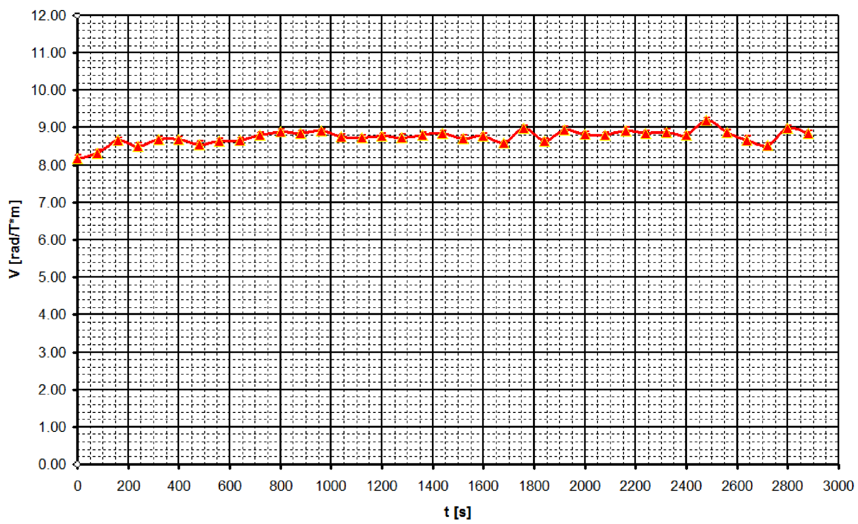

Fig. 12. Time series of magnetooptic sensitivity V measurements. Fiber: IGPCF; wavelength: 405 nm; external disturbation: yes

4. Conclusions

Index guiding photonic crystal fibers show a very good magnetooptic sensitivity value (V=8.75 rad$\cdot$T$^{-1}\cdot$m^{-1}) for the wavelength $\lambda = 405$ nm maintaining simultaneously low sensitivity to external, mechanical disturbances and demonstrating long term stability of magnetooptic sensitivity. It is noteworthy that IGPCFs can operate at several wavelengths simultaneously, which allow to the dynamic adjustment of a measurement range as well as controlling of the measurement system operating condition and selection of optimal working point (operating wavelength and the SOP and the input of sensing fiber).

The small sensitivity value ($\sigma_V = 1.5 \cdot 10^{-2}$ rad$\cdot$T$^{-1}\cdot$m^{-1} for 650 nm; $\sigma_V = 5.1 \cdot 10^{-3}$ rad$\cdot$T$^{-1}\cdot$m^{-1} for 405 nm) of the SOP to external disturbances, described as standard deviation of magnetooptic sensitivity σ_V, in IGPCF requires thorough analysis. Investigations aimed at determination of factors which contribute to it are scheduled in the nearest future. The influence of a size of a IGPCF holes, a distance between them and their number on the SOP stability, will be a goal of immediate investigations.

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