## INVESTIGATION AND IDENTIFICATION OF NOISE SOURCES OF HIGH PRECISION FIBER OPTIC GYROSCOPES *


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**Abstract**

**Key words**: fiber-optic gyroscopes, bias drift, random walk, Allan variance

*At present time fiber-optic gyroscopes (FOGs) with closed-loop feedback scheme of operation are becoming widely used in inertial navigation systems. In the current work the series of devices developed and produced by LLC RPC "Optolink" are discussed. The first group is single-axis fiber-optic gyroscopes (FOGs) with different fiber length and fiber coil diameter: SRS-2000, SRS-1000, SRS-501, SRS-200. The second group comprises three-axis devices (TRS) and inertial measurement units (IMUs): TRS-500, IMU-500, IMU-501. All FOGs are produced in a so-called "minimal" configuration. The major components of FOGs noise and their impact on FOGs accuracy characteristics are identified and investigated.*


At present time fiber-optic gyroscopes (FOGs) with closed-loop feedback scheme of operation are becoming widely used in inertial navigation complexes. In FOGs with closed-loop scheme the feedback mechanism keeps the zero signal level by applying additional phase shift [1-2]. The value of the phase shift allows to obtain information about the angular rate of the device rotation.

Company LLC RPC "Optolink" is the leading Russian manufacturer of FOGs and strapdown inertial navigation systems (SINS) on their basis [3-11]. In the current paper the series of devices developed and produced by LLC RPC "Optolink" are discussed. The first group is single-axis fiber-optic gyroscopes (FOGs) with different fiber length and fiber coil diameter: SRS-2000, SRS-1000, SRS-501, SRS-200. The second group comprises three-axis devices (TRS) and inertial measurement units (IMUs): TRS-500, IMU-500, IMU-501.

Optolink's FOGs are all produced in so-called minimum configuration. FOG tests were conducted at LLC RPC "Optolink" in laboratory conditions at the temperature of 20±0.4˚ C as well as in wide temperature range (from -40˚C to +60˚C) in temperature chambers produced by «Tabai», «Espec» and «Holod» companies. For the estimations of scale factor and zero signal shift at stable temperature as well as in wide temperature range, two-axis rotation table with thermal chamber AC2247-TCM, produced by Acutronic, was used. The duration of tests was at least 10 hours. For the estimations of scale factor and zero signal shift dependence on temperature, data from the devices were collected during gradual temperature change from minimum to maximum acceptable and vice versa. The rate of temperature change varied in range 4˚C/hour – 60˚C/hour.

Due to the absence of domestic state standards (Russian as well as Soviet) of fiber-optic characteristics evaluation techniques, the only international standard in all but name is the standard of Institute of Electrical and Electronics Engineers IEEE Std 952-1997 [12] – Allan variance method – method of bias drift root-mean-square (RMS) representation as a dependence of ($\sigma_A(\tau)$) on the averaging time ($\tau$). Allan variance method relies not on the evaluation of dispersion of averaged random process fluctuations, as it is done in the case of classical dispersion, but on the difference of adjacent fluctuations [12-15]. Relying on the main physical sources of inertial sensors noises, for the FOG signal spectral density in IEEE standard the following evaluation of Allan variance dependence on averaging time is used:

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$$\sigma_A^2(\tau) = R^2\frac{\tau^2}{2} + K^2\frac{\tau}{3} + B^2\frac{2}{\pi}ln2 + N^2\frac{1}{\tau} + Q^2\frac{3}{\tau^2},$$

where N – Angle Random Walk coefficient; B – Bias Instability coefficient; R – Rate Ramp coefficient; Q – Quantum Noise coefficient; K – Rate Random Walk coefficient.

In some cases the approximation could be appended by constituents, corresponding to Markov process (exponentially correlated) and quasiharmonic noises.

Meanwhile, in domestic gyroscopic practice and literature the following method of FOGs parameters estimation is traditionally used by default: FOG signal Bias Drift is assessed as RMS (1σ or 3σ) for 100-second data averaging, and Noise Power Spectral Density (i.e. Angle Random Walk, ARW) is evaluated according to formula

$$ARW = \sigma_{10}/(60\sqrt{f}), \ [deg/\sqrt{hour}] \quad (2)$$

where $f$ is the device bandwidth [Hz], $\sigma_{10}$ – RMS for 10-second data averaging [deg/hour].

This work summarizes taken from the literature data and results for Allan variance testing of world-leading companies' middle- and high- precision FOGs. FOGs Bias Instability and ARW characteristics are illustrated and compared in Table 1. Table 1 and Fugure 1 also illustrate Optolink's middle- and high- precision FOGs Allan variance results (tests were performed by Optolink and other companies).

The main conclusions of the derived results are represented below:

1. Characteristics of high-precision FOGs produced by RPC "Optolink", measured according to international standard (Allan variance method) (see the table below), are on the same level with characteristics of FOGs produced by world-leading companies (Northrop Grumman, IxSea, Honeywell).

Table 1

**Parameters of FOGs produced by world leading and domestic manufacturers**

| Fiber-optic gyroscope | Bias Instability, deg/h | Angle Random Walk, deg/√h | Length (km) and Diameter (mm) of gyro coil |
|---|---|---|---|
| IxSea FOG Marins | 0.0002 | 0.00017 | L=5 km, d=200 mm |
| **Optolink SRS-2000** | 0.00024 | 0.00026 | L=2 km, d=250 mm |
| IxSea FOG180 | 0.0007 | 0.00022 | L=1.5 km, d=180 mm |
| **Optolink SRS-1000** | 0.0006 | 0.0009 | L=1 km, d=150 mm |
| IxSpace Astrix 165 | 0.0008 | 0.0009 | L=2 km, d=200 mm |
| Tokimek | 0.0028 | 0.00078 | |
| Emcore EMP-1.2k | 0.0045 | 0.0017 | L=1.2 km |
| Northrop Grumman LR-240 | 0.0055 | 0.002 | |
| **Optolink SRS-501** | 0.0011 | 0.0023 | L=0.5 km, d=100 mm |
| **Optolink IMU-500** | 0.0025 | 0.0065 | L=0.5 km, d=100 mm |
| **Optolink SRS-200** | 0.006 | 0.008 | L=0.2 km, d=78 mm |
| Fizoptika VG-951 | 0.03 | 0.015 | L=0.2 km |
| Emcore EMP-1 | 0.045 | 0.013 | L=0.2 km |
| Litton LN-200 | 0.07 | 0.056 | |
| KVH DSP 3000 | 0.15 | 0.055 | |

**Calculations were done according to Allan Variance method**

2. Well-established in domestic gyroscopic practices and literature (practically, standard) evaluation of high-precision FOGs accuracy parameters (bias drift) as RMS at 100-second averaging time is not adequate – correlation time for bias instability has a value greater than 1000 seconds. Thus, RMS at 100-second averaging presents information only about the noise power spectral density (Angle Random Walk), but not about the Bias Instability of a gyro.

3. Accuracy parameters of high-precision fiber-optic gyroscopes (Bias Drift and ARW), evaluated according to Russian domestic "standard" (RMS at τ=100sec.), also used in Optolink specifications, are higher (worse), and for bias drift – significantly higher (much worse ~order of magnitude)), compared with characteristics for the same devices evaluated according to the international standard (see Table 2).

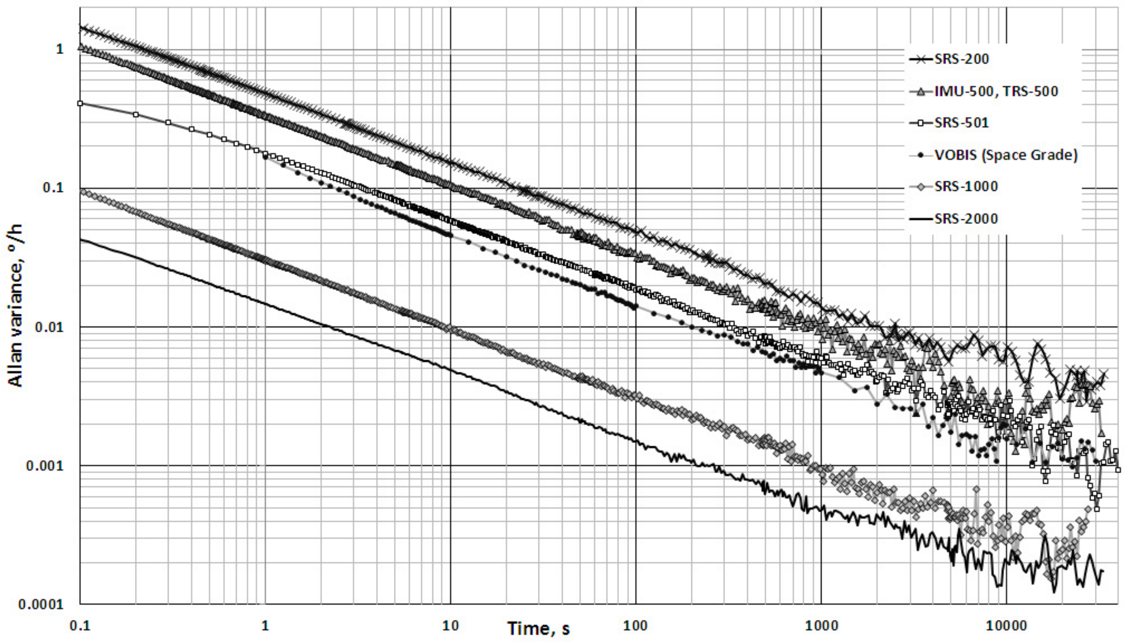
Table 2

**Comparison of FOGs produced by LLC RPC "Optolink" parameters, calculated according to international (IEEE Std 952-1997 – Allan variance method) and domestic standards**

| Fiber-optic Gyroscope | Bias Instability, deg/h | | | Angle Random Walk, deg/√h | | |
|---|---|---|---|---|---|---|
| | "Russian" Standard (τ=100 sec) | Allan variance | Ratio | "Russian" Standard (τ=10 sec) | Allan variance | Ratio |
| SRS-200 | 0,048 | 0,006 | 0,125 (8) | 0,0092 | 0,0081 | 0,87 (1,15) |
| IMU-500, TRS-500 | 0,032 | 0,0025 | 0,078 (12,8) | 0,010 | 0,0068 | 0,66 (1,52) |
| SRS-501, IMU-501 | 0,014 | 0,0011 | 0,078 (12,8) | 0,0065 | 0,0023 | 0,36 (2,8) |
| SRS-1000 | 0,003 | 0,0006 | 0,083 (12) | 0,0008 | 0,00055 | 0,70 (1,45) |
| SRS-2000 | 0,0015 | 0,00024 | 0,125 (8) | 0,00028 | 0,00025 | 0,91 (1,10) |

As a result of conducted research, mathematical model for produced by LLC RPC Optolink FOG noises was defined: Allan variance method allowed to identify the main noise components and to pinpoint the most essential properties of noises for high-precision single-axis FOGs produced by LLC RPC Optolink:

- FOG Bias Instability (Bias Drift),
- FOG angle random walk (ARW).
- In addition, FOG signal could contain:
- noise, corresponding to slope +1/2 on Allan curve (rate ramp);
- Markov noise with correlation time – 1-2 frames of FOG output data;
- noise, corresponding to periodic or/and quasiperiodic random fluctuations.




Allan Variance of FOGs serially produced by LLC RPC Optolink

More detailed information about the FOG noise structure can be obtained using correlation analysis. Autocorrelation functions of FOG signal clearer than Allan variation demonstrate the presence of FOG noises such as white noise, Flicker noises of different types, Markov noise and noises corresponding to quasiperiodic random disturbances (see the right side of Allan Variance curves on figure). Amplitude of quasiperiodic fluctuations could comprise up to 55-60% of overall amplitude of white noise and Markov process. Localization of these noises sources and their decrease in the process of FOGs produced by LLC RPC Optolink further improvement – is the additional reserve in the accuracy increase of FOG and SINS on their basis.

On the basis of obtained data technical improvements were proposed in order to enhance the performance of FOGs and to increase the accuracy of SINSs developed on the base of Optolink's fiber-optic gyros.

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