Ultra-compact navigation-grade Inertial Measurement Unit IMU400

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At present time interferometric fiber-optic gyroscopes (IFOGs) are widely used in inertial navigation systems (INS), and in wide range of applications have replaced its well-established main competitor ring laser gyroscopes (RLG). In high precision closed-loop configuration of IFOG the feedback mechanism keeps the zero signal level by compensating the Sagnac phase shift with additional phase counter-shift. The value of the phase counter-shift allows one to obtain information about the angular rate of the device rotation [1-4]. Due to its inherent low noise and its scalability, FOG technology is one of the very few technologies able to cope with the applications requiring the highest performance combined with cost and SWaP.

Recently, in order to cover the mass-market applications spectrum requiring low-cost and compact inertial sensor yet as much precise as it can be, Optolink has launched new product: ultra-compact navigation-grade inertial measurement unit IMU400. External and internal view (gyro coils) of IMU400 is shown in Figure 1. The aim of the current work was the production of pilot IMU400 devices batch and the estimation of the performance of IMU with direct approach and also with strapdown inertial navigation systems (SINS) simulation methods, which by sense is indirect way of performance observation.

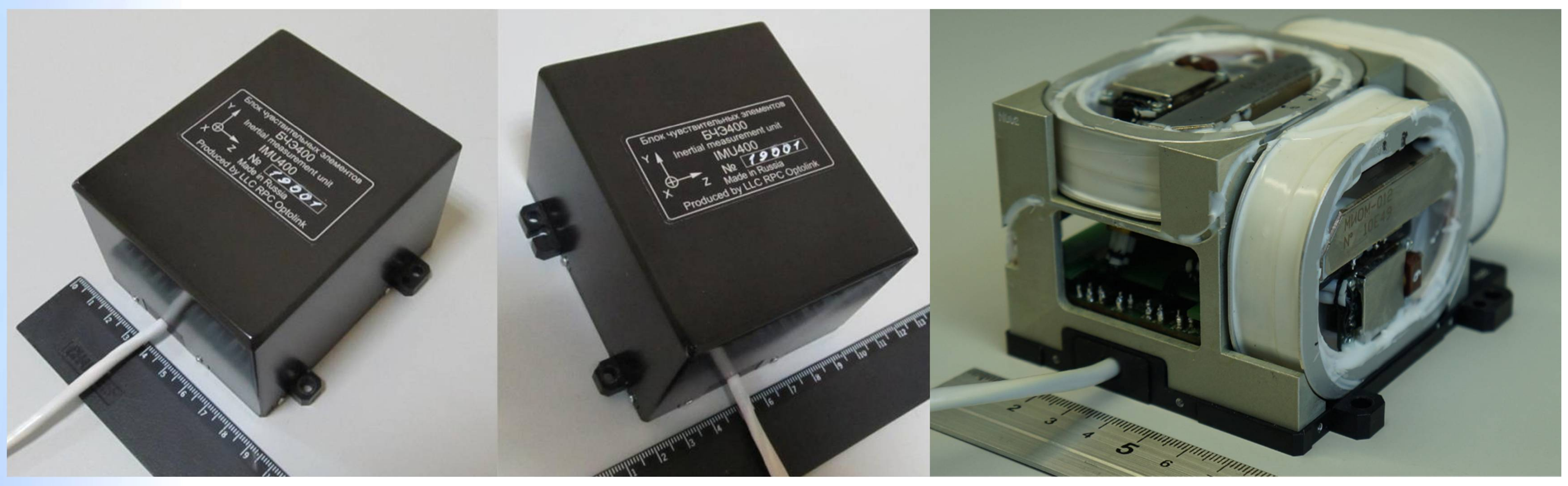

Figure 1. IMU400 external and internal view (gyro coils).

IMU400 SWaP properties are: 80 × 95 × 62 mm, 0.7 kg, 0.5 l, ≤7 W. FOGs are fed with single light source, coils are designed in the shape of rectangle with rounded corners. To cut down the size and cost, regularly used quartz pendulous accelerometers were substituted by MEMS, the IMU has 3 triads (physical) of MEMS accelerometers, with 6 low-noise (composing 2 effective triads) and 3 high-noise acceleration channels which are neglected.

IMU400 specification is shown in Table 1. Its Allan variance among other Optolink's FOGs is shown in Fig. 2.

According to regular Allan Variance plot results (fFg.3) , IMU400 performance values are: - Gyroscope axes (FOG) - ARW 0.007 ° /√hour, bias instability 0.01 ° /hour, run-to-run 0.015 ° /hour, scale factor error 100 ppm; Accelerometers - VRW 40 μg/√Hz, bias instability 6 μg, run-to-run 20 μg, scale factor error 150 ppm.

In Fig. 4 IMU400 bias stability (drift) plots in temperature range -40° C - +60° with constant temperature change rate (ramp) +20° C/hour (20+) and -20° C/hour (20-) are shown. Absolute values are shifted.

In temperature range IMU400 pilot units also shows stable behavior (shown in Figure 4), with gyro and ACC bias drift (100s-averaging RMS, 1σ) of <0.1° /hour and <100μg.

Table 1. IMU400 specification

Performance	IMU400
Gyro	
Angular rate range, °/s	±550
Bias drift at constant temperature (1σ, 100s-averaging), °/h	0.1
Bias drift (1σ, 100s-averaging) in operational temperature range, °/h	0.7 (*0.3)
Angle random walk, °/ √h	0.01
Scale factor error, ppm	500 (*200)
Bandwidth, Hz	> 1000
Accelerometers	
Range, g	±10
Bias drift at constant temperature, mg	1
Bias drift in operational temperature range, mg	1.0 (*0.4)
Scale factor error, ppm	500 (*300)
Noise power density, mg/ √Hz	0.08
Bandwidth, Hz	> 300
Physical Characteristics	
Misalignment, °	0.08 (*0.015)
Output sample rate, Hz	up to 2000
Power supply, V / Consumption, W	5 / 7
Digital output interface	RS-422
Operational temperature range, °C	-40 ~ +60
Dimensions, mm	80 × 95 × 62
Weight, kg	0.7

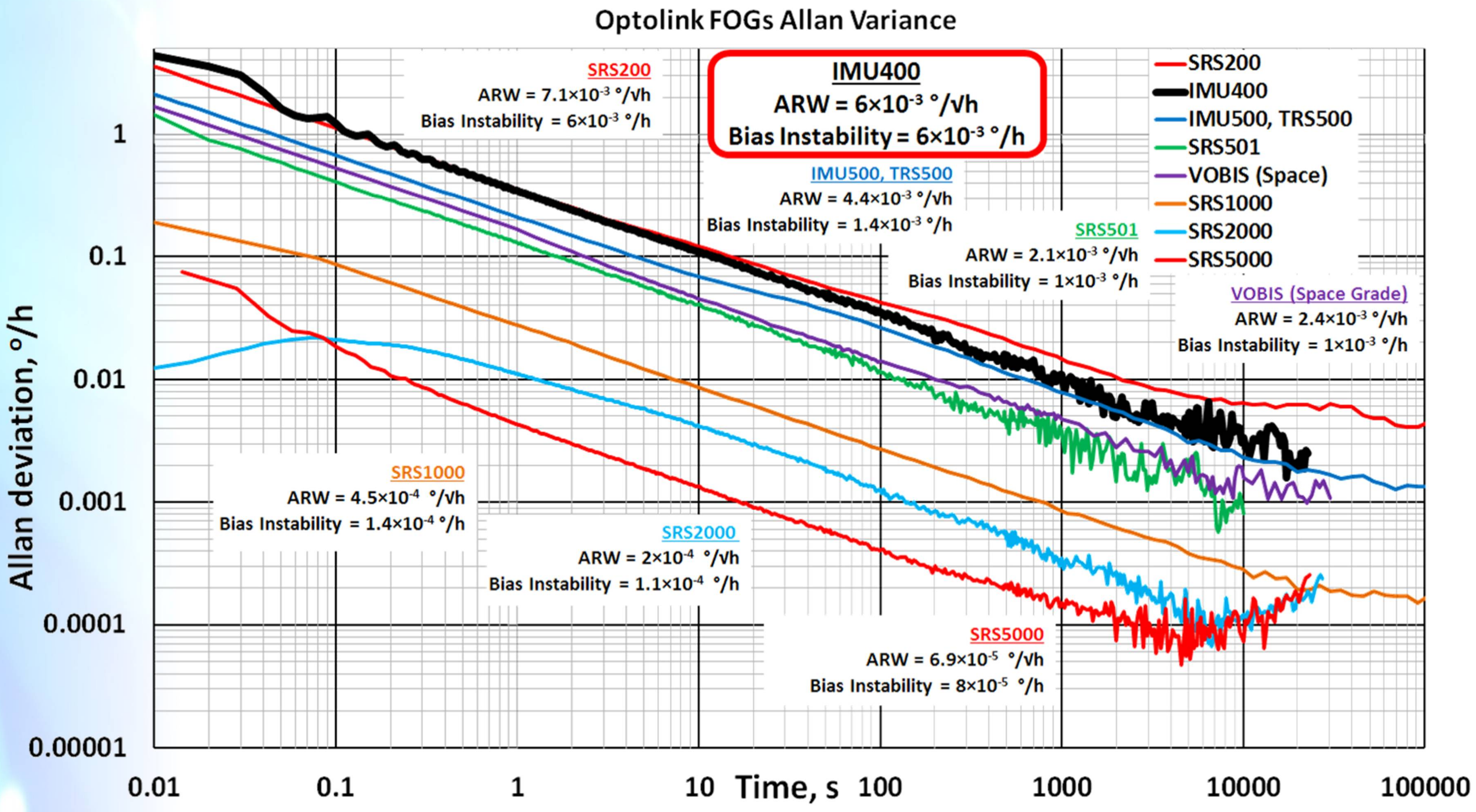

Figure 2. IMU400 Allan Variance plot in Optolink's FOG family

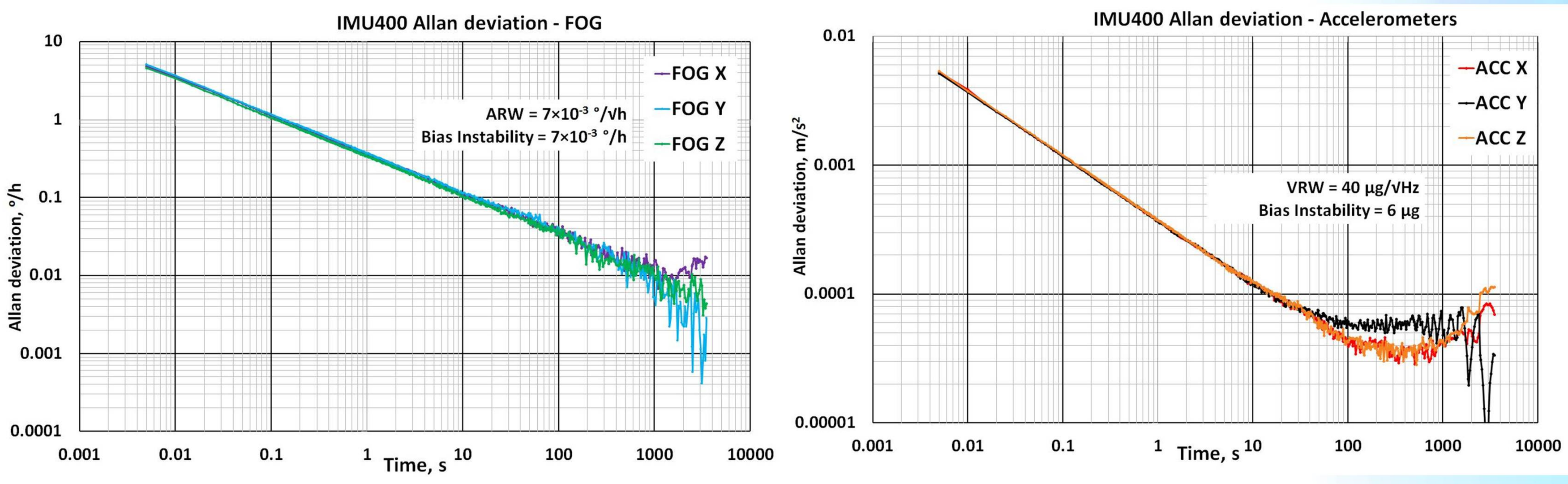

Figure 3. IMU400 FOG and ACC channels Allan variance plots

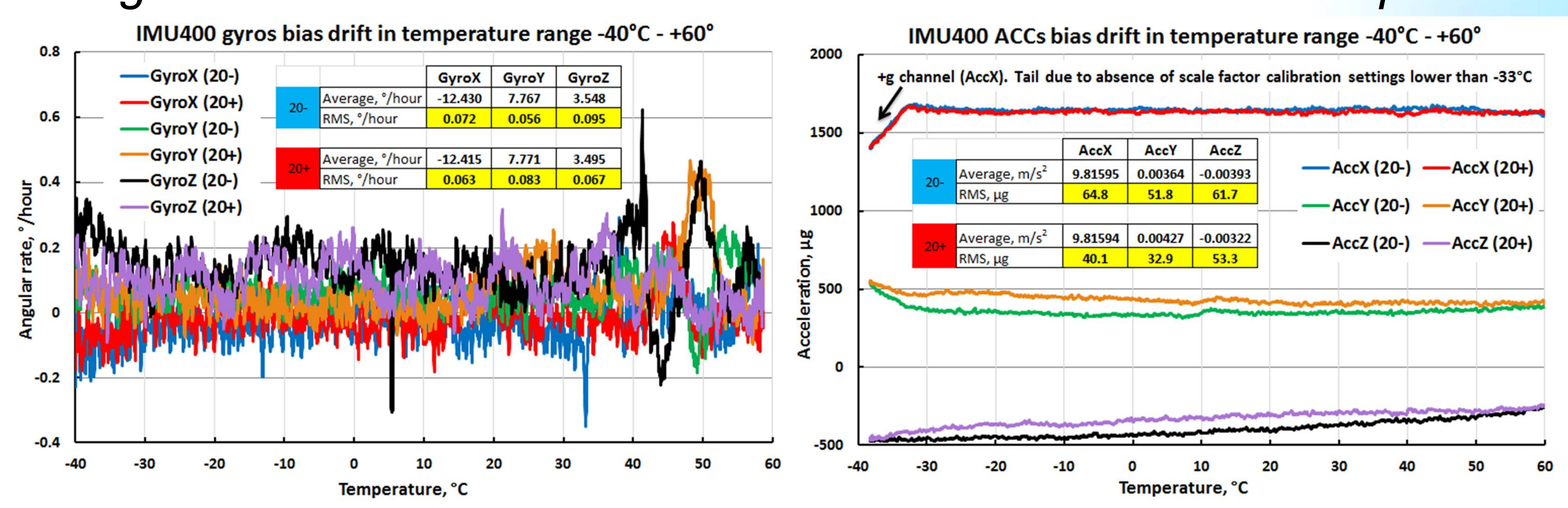

Figure 4. IMU400 Gyroscopes & Accelerometers bias stability plots

At Optolink [5], for SINS certain test procedures are carried out in order to qualify their accuracy level. One of the main and peculiar SINS parameters is the obtained heading accuracy during straightforward alignment in gyrocompassing mode. The performance of IMU400 units was then investigated using these indirect way of measurements (Fig. 5,6).

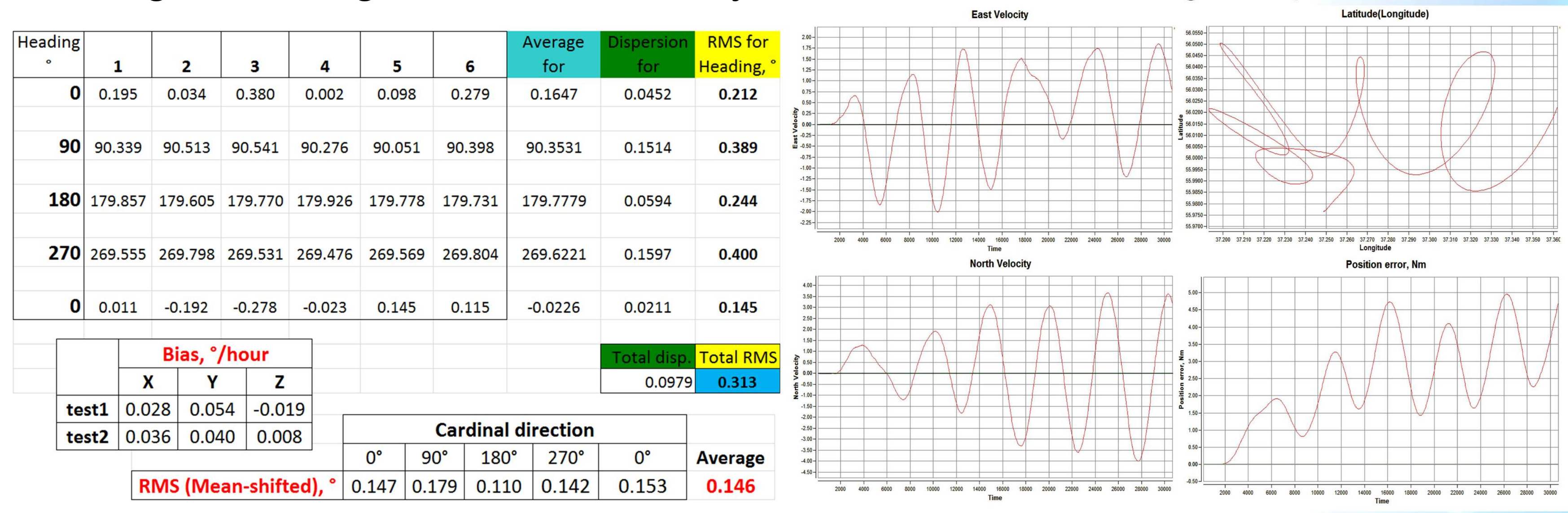

Figure 5. Alignment accuracy & static navigation performance of IMU400 in SINS simulation

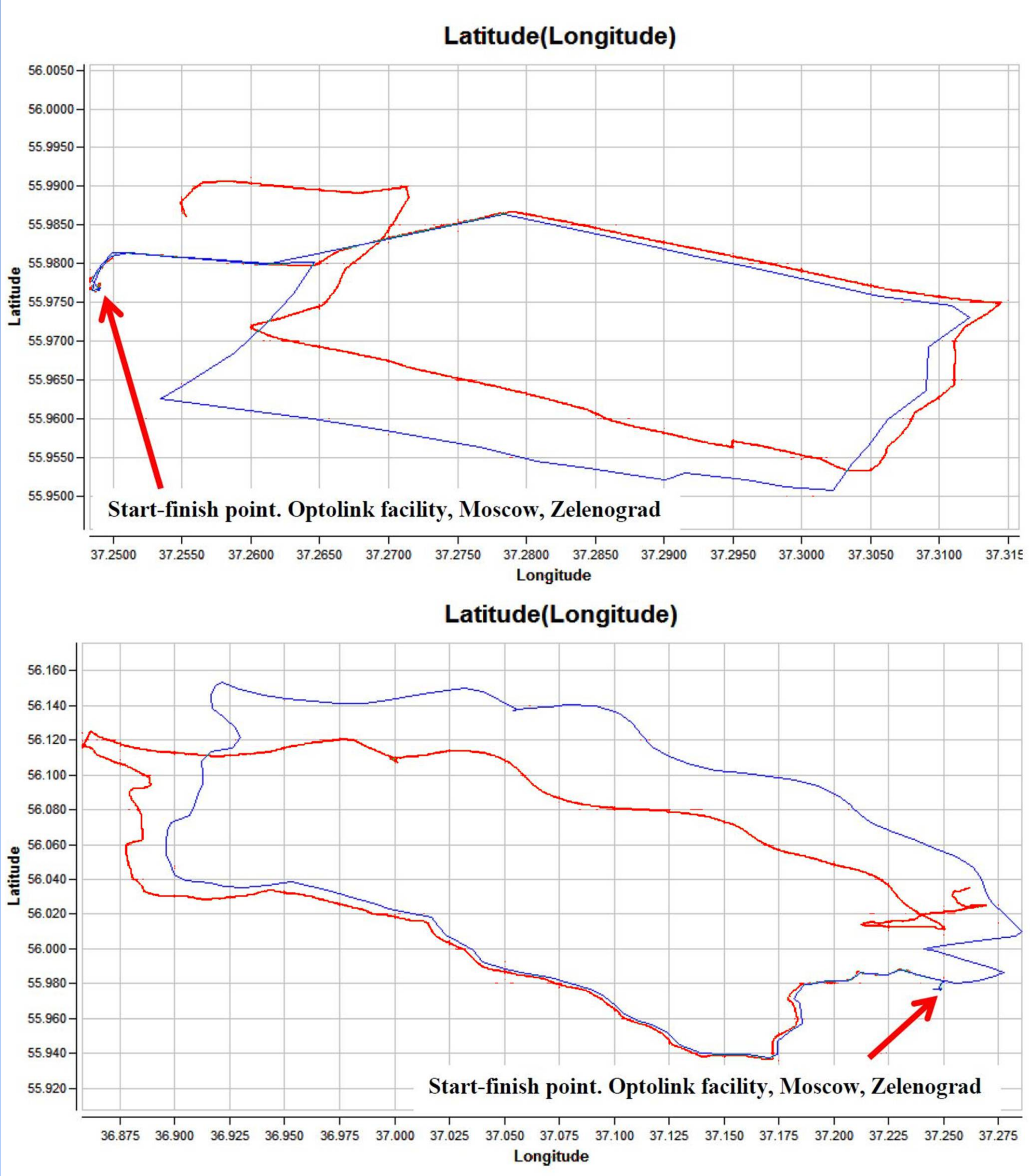

Figure 6. IMU400 navigation performance (2 tracks: 1 – 30 km, 2 – 110 km length)

Statistics show alignment true error (gyro bias + IMU noise) of **0.3° (1σ, 56° N).** After precise accounting for gyro biases, IMU400 in static 5 positions shows coordinates drift of ~5 Nm over 8 hours in pure inertial mode.

In Fig. 6 IMU400 navigation performance in compensated inertial mode (ZUPT) in two data sets on tracks is shown: ~30 km (~1km CPE error), ~110 km (~10km CPE error). Blue is GPS plot, red is IMU track via fwd post-processing. Alignment time is 10 minutes. Shown in Fig. 5,6 values are several orders better than any MEMS or open-loop FOG for the same task (not even measured in pure inertial mode).

The observed performance values allow to assess IMU400 type of devices as navigation or near-navigation grade IMU with unique combination of performance / cost / SWaP characteristics.

[1] H.C. Lefevre, The Fiber-Optic Gyroscope, Second Edition. Boston, Artech House, 2014

[2] W.K. Burns, Ed., Optical Fiber Rotation Sensing, Boston, Academic Press, 1994.

[3] E. Udd and M. Digonnet, Eds., Design and Development of Fiber Optic Gyroscopes, Bellingham, Washington, SPIE Press, 2019.

[4] H.C. Lefevre "The fiber-optic gyroscope: Achievement and perspective", Gyroscopy and Navigation, 2012, Vol.3, pp.223-226.

[5] Yu.N.Korkishko et al., "Strapdown Inertial Navigation Systems Based on Fiber Optic Gyroscopes", Gyroscopy and Navigation, 2014, Vol. 4, No. 4, pp. 195–204.

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