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TECHNICAL DESIGN NOTE

Precision angular velocity response of a fiber-optic gyroscope using a piezo-nano-rotation table

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Abstract
Modern fiber-optic gyroscopes are calibrated using the Earth's rotation or stepper motor actuated rotation tables. We investigated the angular velocity resolution of the Optolink SRS-1000 fiber-optic gyroscope using a piezo-activated rotation table down to angular velocity steps of 1×10^{-7} rad s^{-1} with an accuracy of 1.5×10^{-8} rad s^{-1}. To our knowledge, these are the smallest velocity steps resolved and reported in the literature so far. Our results show that such a gyroscope may be also used for nanopositioning purposes in addition to its usual navigation application.

Keywords: gyroscopes, piezoelectric devices, angular velocity, fiber-optic gyroscope, piezoelectric actuator, nanopositioning, navigation

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Fiber-optic gyroscopes (FOGs) are state-of-the-art rotation rate sensors used for highly-demanding navigation solutions. In general, laser gyroscopes are Sagnac interferometers which use the interference of counter-rotating laser beams to determine changes in the angular position or velocity [1]. FOGs are more advanced devices which guide the laser beam in a long fiber coil, thereby increasing its sensitivity by the number of turns in the coil. Modern FOGs have coils with lengths of kilometers integrated in a device of typically less than 15 cm diameter. The performance of such sensors focuses on the long-term bias and drift stability as well as the random-angle-walk (RAW) which is the sensor's output noise. This is usually done by using the Earth's rotation as a reference while the gyro's axis is tilted between positions parallel and perpendicular to the Earth's rotation axis. Another method is to mount the gyroscope on a stepper motor actuated rotation table [2]. Although the stability at specific velocities can be checked accurately, these methods are less useful to investigate the smallest rotation steps that can be resolved.

Ring laser gyroscopes as well as earlier fiber-optic gyroscope models output an angle which must be differentiated in order to resolve the angular velocity. Modern FOGs can directly output the angular velocity which usually results in a much higher resolution for angular velocities. A comparison between the industry standard ring laser gyro from Honeywell and several FOGs is listed in table 1.

The SRS-1000 has a float number output and therefore the digital resolution is limited by the Earth's rotation offset as the gyro is mounted so that its axis is perpendicular to the laboratory floor. According to the manufacturer, we should therefore be able to resolve angular velocities down to 6×10^{-12} rad s^{-1}, which is some six orders of magnitude better compared to other FOGs like the KVH DSP 3000 and therefore remains doubtful.

Recently, we reported anomalous gyroscope signals with both the KVH DSP-3000 ($1–3 \times 10^{-5}$ rad s^{-1}) and the

Table 1. Gyroscope properties.

Gyro type Spec	Ring laser Honeywell GG1320	Fiber optic IXSEA TRIADE 120	KVH DSP3000	Optolink SRS-1000
Stability (deg h^{-1})	0.0035	0.003	4	0.01
RAW (deg $h^{-1/2}$)	0.0035	0.001	0.067	0.001
Resolution (arcsec)	1.13	0.0012		
Resolution (rad s^{-1})			1.05×10^{-6}	6.44×10^{-12} [a]

[a] Digital resolution limited by the Earth's rotation offset in our laboratory due to the FLOAT number output.

Optolink SRS-1000 (0.2–7 $\times$ 10^{-6} rad s^{-1}) picked up above spinning rings at liquid helium temperatures without any apparent mechanical or electromagnetic coupling [3, 4]. While the DSP-3000 angular velocity resolution was verified with a stepper motor rotation table, angular velocities down to 10^{-7} rad s^{-1} are not easily resolvable. However, we needed to verify if the SRS-1000 gyro can indeed see such small angular velocities as it should according to its specifications. We therefore mounted the gyro on a piezo-activated rotation stage used for nano-positioning. This paper summarizes our SRS-1000 gyro measurements to investigate very small angular velocity steps approaching resolutions of mobile atom interferometers [5].

2. Experimental setup

The SRS-1000 gyro was mounted with screws on top of a ROTOR 10SG rotation stage manufactured by Piezosystem Jena GmbH which was fixed on the laboratory floor. The rotation stage can provide an angle up to 9 mrad with a resolution down to 0.2 μrad. The SG version is equipped with a high-resolution strain gauge measurement sensor that provides a high stability and linearity in combination with a closed loop controller.

The ROTOR 10SG is connected to a 30V300nanoX CLE amplifier also from Piezosystem Jena GmbH that commands the angle on the rotation stage using a 0–10 V input. It also features a calibrated output on the actual position of the rotation stage. The software commands and records the actual position from the amplifier using a National Instruments PCI-6036E data acquisition card in combination with a high-accuracy 100$\times$ analog amplifier. The SRS-1000 gyro has a digital output via an RS-485 interface that is recorded with a LabView program.

3. Measurements

The following data were obtained using a standardized velocity profile which lasts for about 140 s. The profile is subdivided into five sectors with pre-defined time intervals: rest, acceleration, maximum velocity, deceleration and rest. Each profile is repeated first in the clockwise direction (spin vector of ring points downwards) and then in the counter-clockwise direction.

Then the velocity profiles are repeated usually up to 20 times and then the results are signal averaged in order to decrease noise. An example of such a commanded velocity profile is illustrated in figure 1. After signal averaging, the maximum signals were evaluated for their mean value and standard deviation. Figures 2 and 3 both plot the actual angular velocity of the rotation table as well as the gyro output for velocities in the range of 10^{-6} rad s^{-1} to 10^{-7} rad s^{-1} respectively. A linear regression analysis gives a correlation coefficient of 0.999 85 and 0.996 66 for the two plots respectively showing excellent linearity.

Our results show that indeed steps as small as 1 $\times$ 10^{-7} rad s^{-1} can be accurately resolved by the gyro with

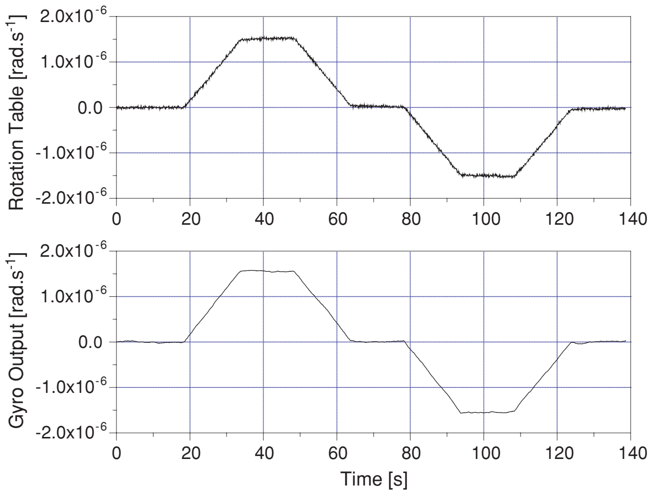

Figure 1. Commanded velocity profile (top) and gyroscope output (bottom).

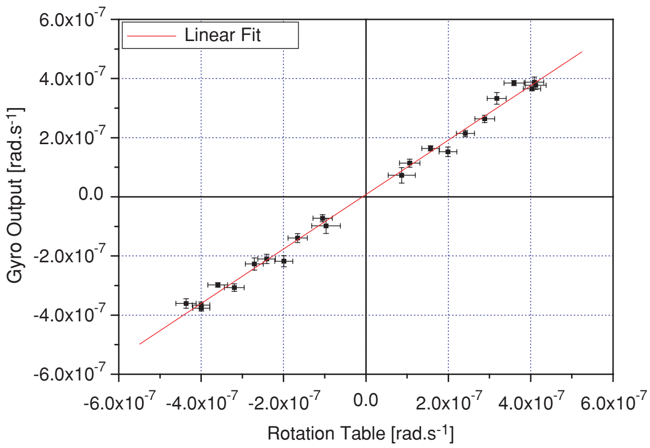

Figure 2. Rotation table versus gyro output for angular velocities ranging from 0.5 to 2.5 $\times$ 10^{-6} rad s^{-1}.

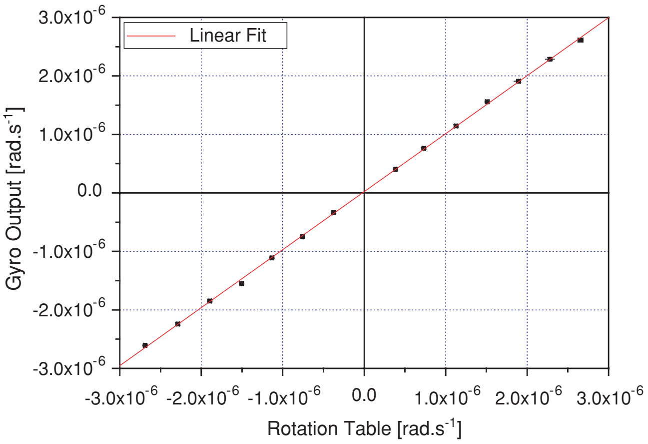

Figure 3. Rotation table versus gyro output for angular velocities ranging from 1 to 4 $\times$ 10^{-7} rad s^{-1}.

an average error of about 1.5 $\times$ 10^{-8} rad s^{-1}. This is an excellent value for a FOG approaching the performance of atom interferometers [5].

4. Conclusion

We have verified the performance of the Optolink SRS-1000 FOG using a piezo-activated rotation table down to angular velocity steps of 1 $\times$ 10^{-7} rad s^{-1} with an accuracy of 1.5 $\times$ 10^{-8} rad s^{-1}. To our knowledge, these are the smallest velocity steps reported in the literature so far. Since the theoretical resolution of the SRS-1000 is in the 10^{-12} rad s^{-1} range, the actual resolution may be better then our measurements since we were limited by the performance of the rotation stage rather than by the performance of the gyro. Due to the high resolution of the Optolink FOG and the compact size (diameter 150 mm, height 38 mm), the gyro may be used for nanopositioning purposes in addition to its usual navigation application.

Acknowledgment

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