Testing a prototype broadband fiber-optic gyro

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Introduction

Requirements for a portable rotational motion sensor

<table>
<thead>
<tr>
<th>Dynamic range</th>
<th>Frequency range</th>
<th>Power consumption</th>
<th>Temperature sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 nrad/s - 5 μrad/s</td>
<td>0.001 Hz - 20 Hz</td>
<td>5 - 8 W</td>
<td>&lt; 0.1%/°C</td>
</tr>
</tbody>
</table>
Introduction

The interferometric fiber-optic gyroscope (IFOG)

Pros:

• Sagnac interferometer
• no moving parts
• flat response over a large frequency range (DC - \(\sim\)kHz)
• inherently not sensitive to translational motion

Cons:

• high sensor self noise in the required frequency band
• high power consumption
The iXBlue Prototype

- Light source
- Detector
- I.O. circuits
- Data and communication port

nominal performance characteristics (from manufacturer):

<table>
<thead>
<tr>
<th>fog</th>
<th>Power [W]</th>
<th>ARW $[m^\circ h^{-1/2}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10cm/1km</td>
<td>8</td>
<td>0.5</td>
</tr>
<tr>
<td>18cm/2km</td>
<td>8</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The sensor unit from iXBlue:

- sensor unit incompliant for navigational purpose
- two sensor coils with different diameter and length (fog10cm/1km and fog18cm/2km)
- RS232-port to readout 100 Hz data (without absolute time stamping)

Our tasks:

- build an appropriate housing
- data acquisition with absolute time stamping

→ focus on the 18cm/2km coil
The iXBlue Prototype

Key features:

- single component
- special housing design allows vertical or horizontal orientation
- 24 V DC power supply
- $l \times w \times h$: 25 cm $\times$ 25 cm $\times$ 27 cm
- $< 10$ W power consumption (including data acquisition system)
- GPS/PPS synchronized Raspberry Pi for data acquisition
Test procedures

Concepts

- **Allan deviation (ADEV):** A measure to characterize the sensor self noise signal in the time domain. With the averaged rotation rate signal $\Omega_k(\tau)$ for an averaging time $\tau$, the Allan deviation is defined as:

$$ADEV(\tau) = \left( \frac{\langle (\Omega_{k+1}(\tau) - \Omega_k(\tau))^2 \rangle}{2} \right)^{1/2}$$

Pure white noise $\rightarrow -1/2$ slope of $ADEV(\tau)$

- **Angle random walk (ARW):** A measure to quantify sensor self noise. Typically: $ADEV(\tau)$ at $\tau = 1$ h

- **Power spectral density (PSD):** A measure to quantify sensor self noise in the frequency domain.

- **Operating range diagram:** A way to make sensor self noise comparable to seismic signals. Integrating the PSD of a self noise signal over half octave frequency bands gives the lower limit of the operating range diagram (Evans et al. 2010, SRL).
Test procedures

Sensor self noise

Record the sensor output without any input ground movement or other ambient noise sources.

- place the sensor next to a traditional broadband sensor (STS2) in a seismic vault
- search for a period with input ground movement as weak as possible

Allan deviation, Power spectral density, Operating range diagram ⇒ Conservative estimation of the upper limit of sensor self noise
Test procedures

Temperature sensitivity

- sensor with sensitive horizontal axis on step table (CT-EW 01)
- heat the whole setup to temperatures of approx. 10°C, 20°C, 30°C, 40°C and 50°C
- wait approx 2 h for each temperature step to reach uniform temperature in the sensor
- generate a constant input rotation
- calculate the scale factor (SF) for each temperature
Test results

Allan Deviation

- white noise over a large frequency range
- angle random walk at 1 h integration time: $0.1 \, \text{m} \, \text{h}^{-1/2}$ matches very well the nominal value.
- $6.3 \, \text{m} \, \text{h}^{-1} \, \text{Hz}^{-1/2} = 30 \, \text{nrads}^{-1} \, \text{Hz}^{-1/2}$ white noise at 1 s integration time
Test results

Power spectral density

- 40 \text{nrads}^{-1}\text{Hz}^{-1/2} \text{ root power spectral density}
- constant power over a large frequency range (0.003 Hz - 10 Hz)
- White noise level is more than one order of magnitude lower than for previously used FOG.
- For frequencies lower than 2 Hz, the noise level is up to two orders of magnitude lower than for liquid based rotational seismometer R1.
Test results

Operating Range

- Yellow stars represent the maximum rotation rate signal from the $M_w 9.0$ Tohoku-Oki earthquake measured by G-Ring in Wettzell, Germany.
- Noise level is low enough to record such large teleseismic events.
Test results

Temperature sensitivity
without temperature modeling!

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>SF [$10^9 (\text{rads}^{-1})^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8</td>
<td>9.899 ± 0.007</td>
</tr>
<tr>
<td>17.4</td>
<td>9.898 ± 0.006</td>
</tr>
<tr>
<td>28.6</td>
<td>9.908 ± 0.006</td>
</tr>
<tr>
<td>43.1</td>
<td>9.932 ± 0.040</td>
</tr>
<tr>
<td>53.8</td>
<td>9.951 ± 0.006</td>
</tr>
</tbody>
</table>

mean value: $(9.918 ± 0.01) \cdot 10^9 \ (\text{rads}^{-1})^{-1}$

temperature sensitivity of scale factor (SF):

$0.01\%/\degree\text{C}$
Conclusion

- **Power consumption**: acceptable for many applications in seismology but still very high compared to other seismic instruments. With very low effort power consumption can be brought to $\sim 4 \text{ W}$.  
- **Sensor self noise**: significant improvement compared to previously used rotational sensors  
- **Temperature sensitivity**: Even without temperature modeling, it meets the requirements for applications in seismology.
Future work

• analyze collocated recordings of ambient noise (small aperture array + iXBlue prototype)

• lab and field tests of a 3-component prototype with even better resolution (\(\sim 20 \text{nrads}^{-1}\text{Hz}^{-1/2}\), BlueSeis-3A launched at the end of the year by iXBlue)

→ for more information please come to the poster by Frederic Guattari
Acknowledgment

www.BlueSeis.com

Thank you!