The investigation of FOG output signal dependency on environment temperature at high rates of temperature change

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Abstract. The development of fiber-optic and electronic components has led to a significant widening of
their application scope, in particular in the construction of ground vehicles navigation systems. Often, such
systems have the special performance requirements under difficult temperature conditions: the environment
temperature changing rate in some cases may reach several °C/min. One of the key elements of a navigation
system is a fiber-optic gyroscope (FOG). The harsh environmental conditions increase the demands on
production technology of the FOG, on the choice of construction materials, on the arrangement and shape
of the parts, etc., however, in order to decrease temperature effects influence on the output signal of the
device, the use of special algorithmic compensation methods is also required. Algorithmic compensation
requires careful preparation of input data, which is associated with extensive experimental work. This
article analyses the FOG temperature dependence characteristics in the wake of the designated experimental
preparation for algorithmic compensation.

1. Introduction
This article is dedicated to the problem of temperature dependency of FOG, particularly to the high
speed temperature change rate (up to several °C/min). Despite the progress in the technology of FOG
manufacturing for the last 20 years the problem of temperature dependency still remains relevant. With
the evolution of material and technical base the FOG application field also grows: FOG based navigation
systems are used in aircraft and ground transportation. Such applications has strict requirements to
system’s weight and size, so temperature sensitivity can’t be solved with an additional thermo-stabilizing
elements such as passive (thermos) or active (Peltier) schemes. Another approach is to research and
develop an algorithm to compensate temperature influence on FOG’s output. This paper provides an
example of temperature compensation based on spatial temperature gradients detection.

The classical compensation method well known in literature [1] appeals to the information about
temperature derivative, showing high correlation with FOG’s error. So, basic angular velocity error is
calculated by equation:

\[
\Omega_{\text{err}} = k_1 T + k_2 \frac{dT}{dt} \quad (1)
\]

where \( \Omega_{\text{err}} \) – angular velocity error, caused by temperature, \( T \) – temperature, \( \frac{dT}{dt} \) – temperature
derivative, \( k_1, k_2 \) – coefficients.
In the article [2] authors describe a method where spatial temperature gradient is also used. However, there are only three temperature sensors, which doesn’t give an information about spatial gradient at all.

In the [3] is shown that spatial gradient should be considered, as much as temperature data with time delay should be added. However, authors used only one temperature sensor, using additional first and second derivative in compensation method.

1.1. Spatial temperature gradient

It should be noted, if the measuring system has a distributed sensitive part, the spatial gradient of the environmental parameters becomes especially important. For an algorithmic compensation a total error signal must include contribution of an each different part of the distributed sensing element. If a direction of an influence is known and the distribution can be considered linear, then there is a possibility to calculate the influence in each point of the distributed sensing part. In this conditions it is possible to compensate such influences by measuring the influence in one point and use the speed of its change – the time derivative – in an algorithmic compensation.

On the other hand, when one of these conditions cannot be met the thermal influence on the different parts of sensor should be taken into account. For example, by using only one temperature sensor in on a whole fiber optic coil (FOC) of FOG there is no opportunity to get any information about the direction of temperature influence.

In a real FOG’s operation conditions the direction of temperature influence can not be stabilized and can not be certainly known. For an effective temperature influence compensation with one temperature sensor the complex of active and passive elements in a FOC’s construction should be used to organize a stable temperature conditions or at least to provide constant direction of temperature gradient [4]. These methods increase mass and size of the end-product and also may increase power consumption.

The alternative approach is to use an array of temperature sensors to detect local value of temperature and compensate the measured angular velocity error.

2. Setup and experiment

Summing up all above gradients in FOC were considered. The FOC were installed in a climatic chamber so that environmental temperature gradients could be uniform. For internal gradients analysis the FOG with eight temperature sensors installed on FOC was used (figure 1).

![Figure 1: Temperature sensors placement scheme](image)

The temperature inside the chamber changed according to the figure 3. The space between the lines of different sensors represents the temperature gradient in the coil. The output of FOG in this experiment is shown on figure 2. Figure 4 shows the temperature derivative; the similarity between angular velocity error and temperature derivative is poor: indeed, correlation coefficient between these two values is 0.6426.
3. Research description
In order to research the influence of temperature gradients the difference between data from pairs of sensors and correlation with angular velocity error were analyzed. Figure 5 shows an example of such difference in points 1 and 6 from figure 1.

The correlation between this data and FOG’s angular velocity error is 0.8057 which is already more than the correlation with temperature derivative.

Using this data the compensation can be achieved with the model:
\[ \Omega_{err} = \sum_{i=1}^{N} k_i T_i + b \]  

where \( N \) – quantity of temperature sensors, \( k_i \) – temperature weight coefficients, \( T_i \) – data from temperature sensors, \( b \) – bias.

Since two sensors cannot fully describe temperature gradient in FOC the additional data from all sensors should be used to compensate temperature induced error. The result of compensation method using spatial temperature gradients is shown on figure 6. The quality of compensations were estimated with standard deviation (STD) and represented in the table 1.

4. Conclusion
This work demonstrated the importance of temperature sensors array usage to detect temperature gradients in FOC. It is shown that the angular velocity error at high rates of temperature change has a greater correlation with spatial gradients, rather than with the temperature derivative. The advantage of compensation based on spatial gradients instead of derivative is shown.
Table 1: Compensation methods comparison.

| Markers on plot | Compensation method                                      | STD, deg/h |
|-----------------|---------------------------------------------------------|------------|
| ○               | Output signal without compensation                      | 1.268      |
| ●               | Compensated with temperature derivative                 | 1.02       |
| □               | Compensated with spatial gradient with 2 sensors        | 0.661      |
| ■               | Compensated with spatial gradient with 8 sensors        | 0.305      |

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