Influence of Stationary and Time-Varying Periodical Interference on Magnetic Sensor Noise Analysis Using Allan Variance

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The Allan variance methodology is a statistic approach, which can be used for the analysis of the noise processes. It can be used for the noise type determination of inertial sensors without the need of any transformations. Although as the Allan variance is a time domain measure, the article deals with the methodology of how to reveal the periodical interference during the noise analysis of magnetic sensors. Subsequently the methodology based on the dynamic Allan variance is applied for the cases, when the periodical interference is non-stationary and varies in time. The noise analysis determining the noise specific types is *inter alia* very beneficial for the in-site or in-flight magnetometer calibration.

1. Introduction

Noise analysis of magnetic sensors can be performed using many methodologies. One of the advantageous methods supported also by the IEEE is the noise analysis using the Allan variance. This method is based on the analysis of a data sequence in the time domain and can also be used to determine the noise types as a function of the averaging period. Currently many optimization methods have been researched [1–3]. We proved that the theory, with some modifications and simplifications, can be applied also for determining the noise type of magnetic sensors [4]. These sensors are nowadays, together with accelerometers and gyroscopes, a common part mainly of the small inertial measurement units. Furthermore, during the noise analysis, it is necessary to consider the characteristics resulting from the time-varying noise amplitude [5]. The Allan variance analysis is the most common time domain measure. However, for the application of the noise analysis using the Allan variance it is advantageous to have methodology to reveal the periodical interference during the noise analysis even in the cases where the periodical interference is non-stationary. This is very important especially if the in-site or in-flight calibration with no magnetic chamber is performed. It is also very advantageous for the utilization of the calibration methods based on the neural networks, which can be influenced by the particular noise types [6].

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2. Stationary periodical interference

The methodology for the noise analysis using the Allan variance that we applied to the magnetic sensors is in detail described in [4]. However, the methodology does not involve the influence of the periodical interference on the noise analysis. That was the reason why the simulation model representing output sensor signal with the duration of 1000 s using the sampling frequency of 1 kHz was created.

In the first simulation the signal involved also the 50 Hz industrial frequency and three output signals marked as y_0, y_1, and y_2 were used. The output signal varied only in the noise amplitude of the signal, which was set to 1 in the case of the y_0 signal. The amplitude of the periodical interference was ten times higher for the signal y_1 and ten times lower for the signal y_2.

The results of the noise analysis using the Allan variance methodology with non-overlapping samples were processed and visualized in the form of the log–log plots. One of the advantage of this methodology is that the noise type can be clearly seen because it is dependent on the slopes of the curves in the particular regions of the averaging period τ. From the results shown in Fig. 1 significant deviations from the ideal linear slopes can be seen in the form of the peaks caused by the periodical interference. Furthermore, it can be seen that the periodical interference has no influence on the noise type. The calculated characteristics vary only in the amplitudes. Although in comparison to the sensor output signals that varied with the step of one decade, it is necessary to take into account that in case of the Allan variance analysis this difference is two decades.
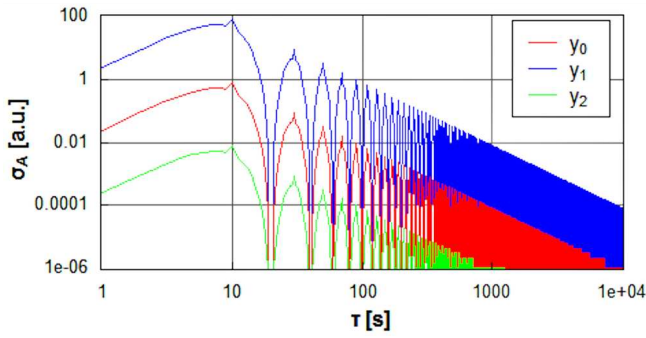
Fig. 1. Allan variance calculated for the stationary periodical interference signals with different amplitudes.

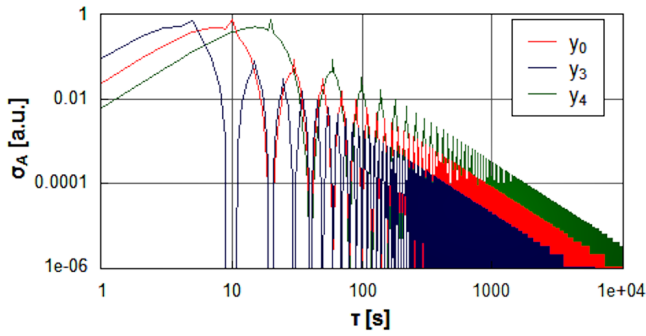Fig. 2. Allan variance calculated for the stationary periodical interference signals with different frequencies.
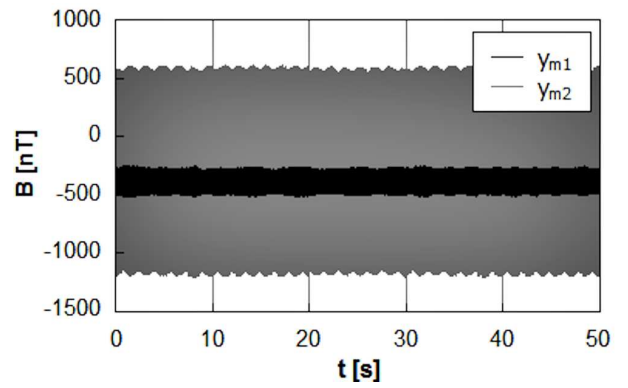

Fig. 3. Measured signal with the stationary periodical interference.
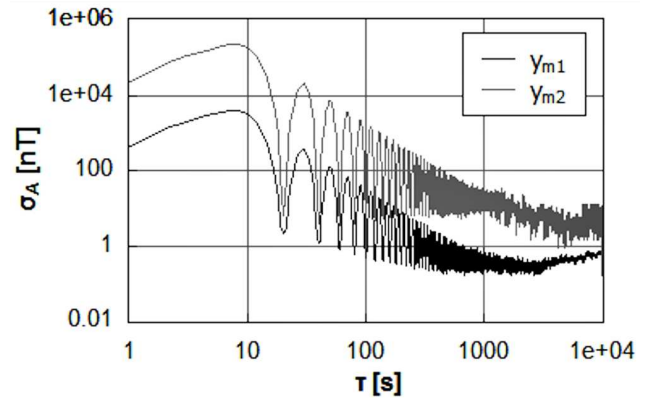
Fig. 4. Allan variance calculated for the measured stationary periodical interference.

The second series of simulations were focused on the influence of the changing frequency of the interference signal. In this case the signal y_0 was compared to other two signals varying only in the used frequency of the interference signal. In case of the y_3 signal it was 100 Hz and in case of the y_4 signal it was 25 Hz. The influence of the frequency of the periodical interference can be clearly seen from the simulation results shown in Fig. 2. If the frequency of the interference is twice higher or lower, we get in the Allan variance characteristics twice more or less number of peaks, respectively. It is important to notice that the amplitudes of the peaks remain the same, which is very important for the determination of the noise type parameters.

Consequently, the simulation results were verified experimentally. Measurements were performed using the VEMA-04 magnetometer based on the magnetic microwires [7]. In Fig. 3 two data sets are shown. The sensor signal marked as y_{m1} represents the reference signal with the unfiltered industrial 50 Hz frequency and the sensor signal designated as y_{m2} represents the output signal of the sensor, in which the transformer load was switched on near the sensor, which caused a significant difference in the interference signal amplitude, whereas the dominating frequency remained the same. The standard deviation of the measured signal changed from 52 nT to 488 nT.

In Fig. 4 the Allan variance calculated for the y_{m1} and y_{m2} signals is shown. From the calculated characteristics we can see that for lower averaging period until the 10^3 s the white or quantization noise is dominant. Then the slope changes to the random walk due to the bias instability in the sensor output in case of the y_{m1} signal. A very similar trend is observed also in the case of the y_{m2} signal with negligible differences of the slopes mainly in the higher averaging periods, where the influence of the bias instability occurs. However, the significant difference can be seen similarly to the performed simulations in the amplitudes. Oscillations in the characteristics are caused by the dominant 50 Hz industrial frequency.

3. Time-varying periodical interference

In addition to the changing amplitude or frequency of the examined signal with the periodical interference, the non-stationary behavior over time was simulated. In the first case of the simulated signal y_5, the step change of the periodical interference amplitude between the y_0 and y_1 in the time of 0.5 s was analyzed. Analogically, in case of the y_6 signal, the step change of the periodical interference amplitude between the y_1 and y_0 signals in the
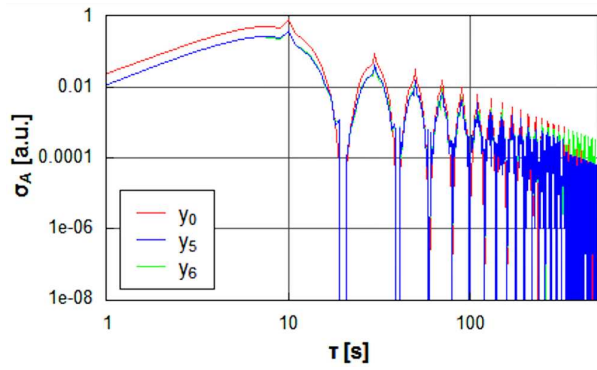
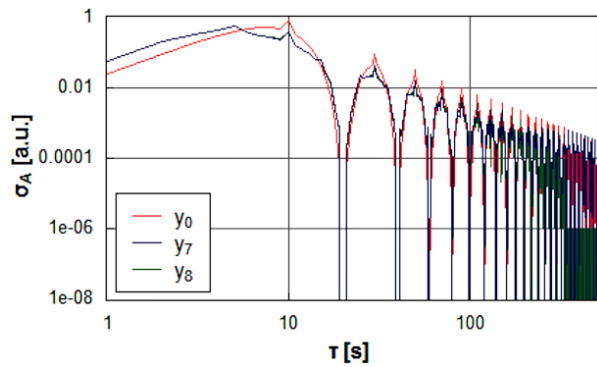Fig. 5. Allan variance calculated for non-stationary periodical interference signals with different amplitudes.

Fig. 6. As in Fig. 5, but for different frequencies.

Fig. 7. Allan variance calculated for the measured non-stationary periodical interference.

time of 0.5 s was analyzed. The second simulation model was created so that the signal marked as y_7 involved step change of the frequency in the time of 0.5 s between the y_0 and y_3 signal (from 50 Hz to 100 Hz) and analogically in the signal y_8, the step change of the frequency from y_3 to y_0 was simulated. Figures 5 and 6 show the comparison of the simulation results and the reference y_0 signal. For the purposes of the time-varying periodical interference signal analysis the simulation model consisting only 10^3 samples was used.

The reason can be clearly seen from Fig. 5 and Fig. 6. The deviations among the signals can be seen only for the higher values of the averaging period and from the models created from more samples as they are negligible in the log–log scale. The simulation results also confirmed that in case of the non-stationary noise analysis of the signals involving the non-stationary periodical interference, the conventional Allan variance approach is not satisfactory for the noise analysis. That is the reason why we decided to apply the theory of dynamic Allan variance for the noise analysis of the magnetic sensor signals with the time-varying periodical interference in more details described in [8]. The theory was confirmed by experimental measurements performed using the same measurement chain as in case of the stationary measurements. The non-stationary sensor signal y_{m3} involved
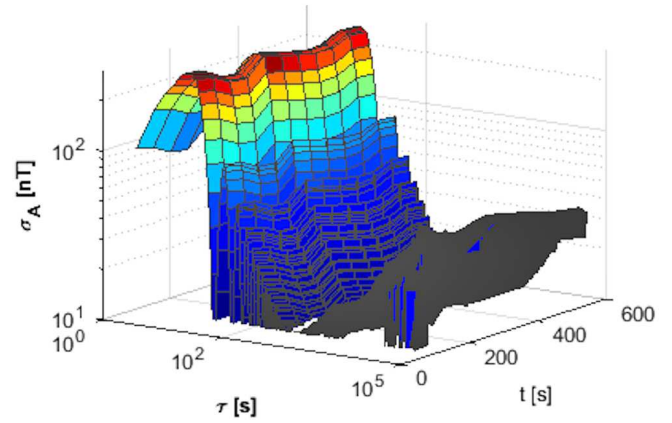
the step changes of the interference signal amplitudes, in which the transformer load was switched on near the sensor in three time intervals — after 60, 360, and 510 s with the duration of 60 s.

From the calculated characteristics shown in Fig. 7, we can see that for lower averaging time until 10^3 s the white or quantisation noise is dominant. Then the slope changes to the random walk due to the bias instability in the sensor output. The non-stationary periodical interference caused only negligible differences of the slopes, but the significant influence can be seen in the form of the oscillations in the characteristics and also in the amplitudes in the time intervals, when the transformer was switched on.

4. Conclusions

The statistical methodology of the noise analysis based on the Allan variance in comparison to other conventional statistical methods has several significant advantages. There is no need of any transformation, which is one of the preferred methods for the identification of the inertial sensors noise types. As it was confirmed in the article, in the conventional form or in the extended version named dynamic Allan variance, it can be very effectively used for the revelation of the periodical interference in the inertial sensor output signal. This was proved by the simulations and also by the experimental results for the stationary and non-stationary interference behavior, which is very important for the selection of the suitable calibration algorithm especially if the in-site calibration based on the neural networks is applied.

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