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Research of digital signal processing methods on the basis of the wavelet transformation for signal processing from a position sensor of the angle-component solvers

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Abstract
The paper considers the problem of measurement of signal parameters from the angle-component solver sensors. The complex Morlet's wavelet, on the basis of which the amplitude ratio and the phase difference between signals of output windings is measured, was used to solve this problem. During the work on the basis of mathematical modeling in MATLAB medium were got the theoretical results, the field research of an algorithm and its results comparison with other algorithms are conducted..

Keywords: position measurement, angular position sensor, wavelet transformation, Morlet wavelet, ACS.

Introduction
The angle-component solvers (ACS) are widely used as a sensor for the angular position measurement in critical parts of aircrafts and other fields demanding high precision, reliability and wide temperature range of the work. Thus, during exploitation the sensors' signals are affected by leakages, hindrances and nonlinear effects which considerably increase signal parameters estimation error.
An angular position is calculated on currents which are induced on two output windings of a sensor by a field signal of primary winding. Thus, output signals are considerably affected not only by the signal generation device and design principles of a sensor, but also the ways of sensor activation [1, 2]. Nevertheless, it does not completely solve the problem of parasitic effects that demands the additional digital signal processing.
As a rule, for signal parameters assessment a time slot of no more than one signal cycle is used that imposes a considerable limitation on the choice of digital processing methods. Thus, most of the methods are very sensitive both to the noise and a signal constant component. The methods are actively developing where the signal parameters measurement is made both with the use of valid wavelets, where thus it is possible to estimate only the signal power, and complex ones which allows also receiving the phase characteristic of signals [3-6].
The paper proposes conducting an analysis of sensor signals and its modeling for the theoretical research of an algorithm of determination of the amplitude and phase of a signal on the basis of the complex Morlet's wavelet, and also carrying out the field research of on algorithm.

Analysis of position sensor signals
The signal with a frequency of 400 Hz to one of the intput windings was given to the angle-component solver input, the second input winding was loaded with the resistance. Figure 1 presents the studied signal spectrum at the sensor output.

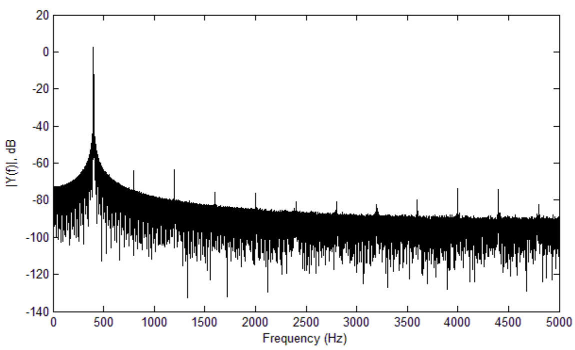

Fig. 1. A signal range at an output sensor

To the device input two signals with equal frequency, but with different amplitudes and phases of the following type are received:

$$
\begin{aligned}
s_1(t) &= \cos(\omega_0 t + \phi_1) + 0{,}1\cos(2\omega_0 t + 2\phi_1) + \\
&+ 0{,}05\cos(3\omega_0 t + 2\phi_1) + \\
&+ 0{,}05\cos(10\omega_0 t + 2\phi_1) + \xi_1(t) \\
s_2(t) &= A_2\cos(\omega_0 t + \phi_2) + 0{,}1\cos(2\omega_0 t + 2\phi_2) + \\
&+ 0{,}05\cos(3\omega_0 t + 2\phi_2) + \\
&+ 0{,}05\cos(10\omega_0 t) + \xi_2(t)
\end{aligned} \qquad (1)
$$

where ω0 – is signal frequency, φ – is the phase, ξ (t) – is white Gaussian noise.
The final device supposes that the signal is digitized by ADC with the following parameters: 13bit@400kSPS, 14bit@200kSPS, 15bit@10kSPS.

Digital signal processing on the basis of wavelet transformation

Let's consider the complex Morlet's wavelet which has only real component as a result of Fourier's transformation [7]

$$\psi(t) = \pi^{-0.25} e^{-j\omega_0 t} e^{-\frac{1}{2}t^2}$$

Because we know the main signal frequency, we will use the following Morlet's wavelet form:

$$\psi(t,a) = \pi^{-0.25} e^{-j\omega_0 t} e^{-\frac{1}{2}\left(\frac{t}{a}\right)^2}$$

where *a* – is a scale coefficient
Wavelet transformation assumes the convolution of the original signal and considered wavelet:

$$W(t,a) = \frac{1}{a}\int_{-\tau_0}^{\tau_0} s(\tau)\psi(t-\tau,a)d\tau$$

where τ_0 - half-cycle signal duration, s (τ) - digital signal circle.
Because the complex Morlet's wavelet is used, the result of convolution is also represented by a complex number on the basis of which it is possible to estimate the amplitude ratio and the phase difference of signals [3].

$$\frac{A_1}{A_2} = \sqrt{\frac{\mathrm{Re}W_1^2 + \mathrm{Im}W_1^2}{\mathrm{Re}W_2^2 + \mathrm{Im}W_2^2}} \qquad (2)$$

$$\phi_1 - \phi_2 = \arctan\left(\frac{\mathrm{Re}W_1 \cdot \mathrm{Im}W_2 - \mathrm{Re}W_2 \cdot \mathrm{Im}W_1}{\mathrm{Re}W_1 \cdot \mathrm{Re}W_2 + \mathrm{Im}W_2 \cdot \mathrm{Im}W_1}\right) \qquad (3)$$

The research of the algorithm on the basis of a signal theoretical model

We investigate behavior of the algorithm during an analysis of one signal period without the noise with the following input signal parameters (1). The noise power ζ (t) is 70 dB without the quantization noise. The following signal parameters are taken: $\varphi_1 = 45^o$, $\varphi_2 = 5^o$, $A_2 = 0{,}5$B.
Figure 2 shows errors of the amplitude ratio and the phase difference definition of input signals without the noise, its existence and ADC parameters 15bit@100kSPS due parameters assessment on the formulas (2) and (3). For ease of an analysis the noise will be generated once and later the temporary dependence will be equal on all iterations.

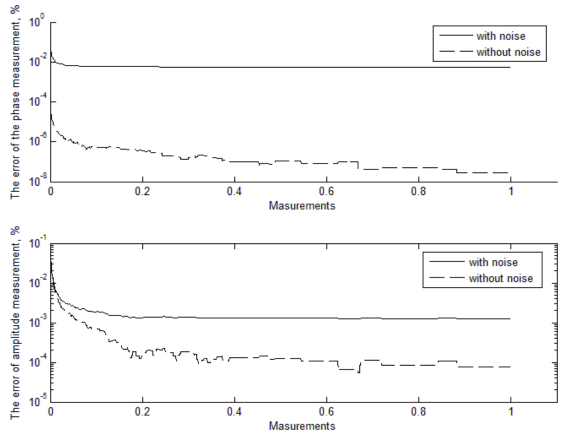

Fig. 2. Dependence of the error at various scale coefficients

Figure 3 shows the result of 1000 measurements of the amplitude ratio and the phase difference of signals at various temporary signal realizations. As figures 2, 3 show the error of the phase difference definition of signals is rather higher than the amplitude ratio assessment of signals, but at increasing amplitude ratio the speed of error reduction of the phase definition is more than the amplitude error reduction speed.

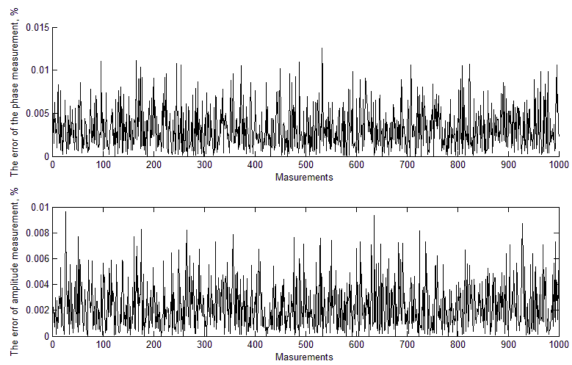

Fig. 3. Measurements errors at different temporary noise realizations

The research of the system error behavior at various modes of signal digitization was conducted: 13бит@400kSPS, 14бит@200kSPS, 15бит@100kSPS. The scale coefficient value was accepted equals a = 0,4. As a result of researches the average values and the mean square deviations (MSD) at various transformation parameters that the table 1 gives are received. In the course of the research two signal periods were used, the second one is received making a copy of the first, a number of measurements was 1000.

Tab. 1. Measurement errors at various ADC operating modes

Operating mode ADC	15бит @100kSPS	14бит @200kSPS	13бит @400kSPS
Average error of phases difference, %	0.0064	0.0045	0.0031
MSD of the phase difference error, %	0.0049	0.0034	0.0024
Average error of the amplitude ratio, %	0,0049	0,0032	0,0023
MSD of the amplitude ratio error, %	0,0034	0,0024	0,0017

Experimental results

The equipment which functional scheme the figure 4 presents was used for conducting the experiment 4. The laboratory source which was generated and gave a sine signal to one of the converter windings was used as a generator , the second winding was loaded with the R1 resistor which resistance is equal to the source resistance. The LabView cRio system serves for digitization of signals which occur on R2 and R3 resistors which transferred to the personal computer for the further data processing. The used equipment allows digitizing a signal with the frequency of 100 kHz and capacity of 12 bits.

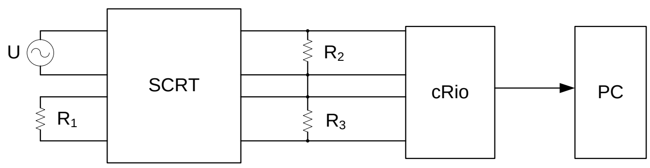

Fig.4. The functional scheme of the experimental installation

For measurements results assessment several algorithms were used: calculation of the mean square value (MSV) of signals, measurement of the signal amplitude, calculation of the wavelet transformation. In addition, for calculation of the MSV and amplitude two bandpass filter of the 4th order with the signal resonance frequency and a pass-band of 20 and 100 Hz were used. Thus, the group delay of a signal was 2500 and 1000 reading respectively that is not always possible to use in practice. The table shows the results of the MSD of measurements, there were conducted 1000 measurements.

Tab. 2. the results of field researches of the algorithms

ADC operating mode	12бит@100kSPS
Wavelet transformation, % SKO	0,0069
Calculation of the MSV, MSD of %	0,0074
Measurement of the excursion, % MSD	0,0664
Calculation of the MSV filter of 20Hz, % MSD	0,0108
Calculation of the MSV filter of 100Hz, % MSD	0,003
Excursion measurement, the filter of 100Hz, % MSD	0,0623

The wavelet transformation has showed the results which are almost the same as the MSV calculation without the harmonic components, so, it is possible to claim that in the linear operation of a sensor the application of the algorithm of the MSV calculation is more appropriate than the wavelet transformation for definition of the amplitude ratio of signals, because of smaller complexity of the MSV algorithm.

Conclusion

The paper offers the programmatic decision of the quality measurement improvement both of a parameter, amplitude, and signal phase. The offered algorithm is investigated both on the theoretical model of a signal, and according to its practical application. The paper has shown that the offered algorithm gives the best results without a considerable delay of results measurement. Also the offered algorithm has much the best results in the presence of harmonic components in comparison with other algorithms.

The application of this algorithm for signal parameter measurement is appropriate when it is necessary to measure the signal phase or only amplitude, but in existence of additional harmonic components.

The noise suppression at the fixed digitization frequency is carried out with higher quality, at the increasing digitization frequency a signal, at the same realization duration. Also, the algorithm is insensitive both to phases of useful signals and its harmonic components.

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References

[1] Zijian, Zhang, 2012. A Novel Absolute Magnetic Rotary Sensor. Industrial Electronics, IEEE Transactions on (Volume:62, Issue: 7), IEEE, pp. 4408 - 4419.

[2] Chang-Sung, Jin, Jang, Ik-Sang, Bae, Jae-Nam, Lee, Ju & Kim, Won-Ho, 2015. Proposal of Improved Winding Method for VR Resolver. Magnetics, IEEE Transactions.

[3] Potekhin, D.S., 2011 Integrated method of the vector scheme recovery in digital data processing

systems.//Control systems and information technologies, № 2.1(44), pp. 161-164.

[4] Hui, Li, 2010. Complex Morlet wavelet amplitude and phase map based bearing fault diagnosis. Intelligent Control and Automation (WCICA), 2010 8th World Congress on, IEEE (issue 8), pp. 6923 - 6926.

[5] He, Wei & Yang, Honggeng. Power Quality Disturbances Classification Based on Second Generation of Wavelet Transform and Vector Quantization Theory. Power System Technology, 2007, 31 (12), pp. 82 - 86.

[6] Gong, Jing, 2009. The Phase Difference Method for Power Quality Disturbance Signals Detection Based on Complex Wavelet Transform. Energy and Environment Technology, 2009. ICEET '09. International Conference on (Volume:2), IEEE, pp. 348 - 351.

[7] Konstantinos, C. Gryllias & Ioannis, A. Antoniadis 2013. Estimation of the instantaneous rotation speed using complex shifted Morlet wavelets. Mechanical Systems and Signal Processing, 38 (1) pp. 78-95.