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INVESTIGATION OF CORRELATION MEASURING METHOD ACCURACY FOR TWO TYPES OF TEST SIGNALS

Summary. On the base of developed computer simulation program the comparative investigations of correlation measuring method accuracy with two types of test signals have been provided.

BADANIE DOKŁADNOŚCI METODY POMIARU KORELACJI DLA DWÓCH RODZAJÓW SYGNAŁÓW PRÓBNYCH

Steszczenie. Porównawcze badania dokładności metody pomiaru korelacji dla dwóch rodzajów sygnałów próbnych zostały przedstawione na podstawie opracowanego programu symulacji komputerowej.

1. INTRODUCTION

Development of railways computer control systems taking place in recent years resulted in advanced requirements for quality of telecommunications lines. To ensure necessary level of lines reliability with simultaneous decrease of their maintenance costs it is necessary to provide continuous computer control of line parameters. Among a great number of methods used for this purpose, the correlation method has some advantages [1-3]. The method is based on calculation of cross-correlation function $R_{xy}(\tau)$ of object input $x(t)$ and output $y(t)$ signals. For providing high accuracy of the method in a voice-frequency range the near even amplitude-frequency characteristic (AFC) of a test signal is necessary and for continuous measurements in inaccessible circuits without their switching off the duration of test signals must be less than average statistical pause in a pulse sequence [1,3]. The noise-type signals in a form of pseudo-random pulse sequence satisfies both conditions but the measurement accuracy of correlation method with such test signals is lower than to determinate short pulse signals in the form of $\sin(t)/t$ and $\delta(t)$ - functions [3].

So this work aimed at providing comparative investigations of object characteristics measurements accuracy by correlation method in a voice-frequency range with two types of test signals ($\sin(t)/t$ and $\delta(t)$) in telecommunications wire lines in a presence of Gaussian noise.

2. THE MEASURING METHOD

The correlation method based on the following theoretical expressions. The cross-correlation function $R_{xy}(\tau)$ of input $x(t)$ and output $y(t)$ signals is equal

$$R_{xy}(\tau) = \int_0^\infty y(t)\,x(t-\tau)\,d\tau = \int_0^\infty R_{xx}(\tau-\theta)\,p(\theta)\,d\theta \qquad (1)$$

where $R_{xx}(\tau)$ – autocorrelation function, $p(t)$ – the pulse characteristic (PC) of investigated object. From expression (1) known in cybernetics as Vinner-Hopf formula, it was obtained for $R_{xx}(\tau-\theta)=\sigma_x^2\delta(\tau-\theta)$

$$R_{xy}(\tau) = \int_0^\infty \sigma_x^2 \delta(t-\tau) p(\theta)\,d\theta = \sigma_x^2\, p(\tau) \qquad (2)$$

where σ_x^2 - average power of input signal.

From (2) the pulse characteristic is equal

$$p(\tau) = \frac{1}{\sigma_x^2}\cdot R_{xy}(\tau) \qquad (3)$$

Object transitive characteristic (TC) was obtained by integration pulse characteristic and amplitude-frequency characteristic (AFC) and phase-frequency characteristic (PFC) were obtained by a direct Fourier transform of the PC:

$$W(j\omega) = \int_{-\infty}^{+\infty} p(t)\exp(-j\omega t)dt \qquad (4)$$

$$A(\omega) = |W(j\omega)|, \qquad \varphi(\omega) = \arg W(j\omega) \qquad (5)$$

According to (3-5) the block-diagram of a computer program for investigation of measurement accuracy of correlation method was developed (Fig.1). It includes a correlometer, integrator, direct Fourier transformer and a comparison block to provide the accuracy measurements by comparison of the measured characteristics and the calculated object characteristics.

Investigations of correlation method accuracy were carried out on the basis of simulating program. The object in a form of oscillatory unit with transfer function was chosen for the measurements

$$W(s) = \frac{k_1}{T_1^2 s^2 + 2\xi T_1 s + 1}, \quad 0 < \xi < 1 \qquad (6)$$

where k_1 - amplification coefficient, T_1 – time constant, ξ – decrement factor.

To estimate accuracy of correlation method the electrical object characteristics were calculated preliminary according to known electrical scheme of oscillatory unit. A pulse characteristic was calculated by expression

$$p(t)=\frac{k_1}{T_1\sqrt{1-\xi^2}}e^{-\frac{\xi}{T_1}t}\sin\frac{\sqrt{1-\xi^2}}{T_1}t,\quad t\geq 0 \tag{7}$$

transitive characteristic

$$h(t)=k_1\left[1-\frac{1}{\sqrt{1-\xi^2}}e^{-\frac{\xi}{T_1}t}\sin\left(\frac{\sqrt{1-\xi^2}}{T_1}t+\varphi_1\right)\right] \tag{8}$$

where $\varphi_1 = arctg\sqrt{1-\xi^2/\xi}$, $t\geq 0$, and AFC PFC

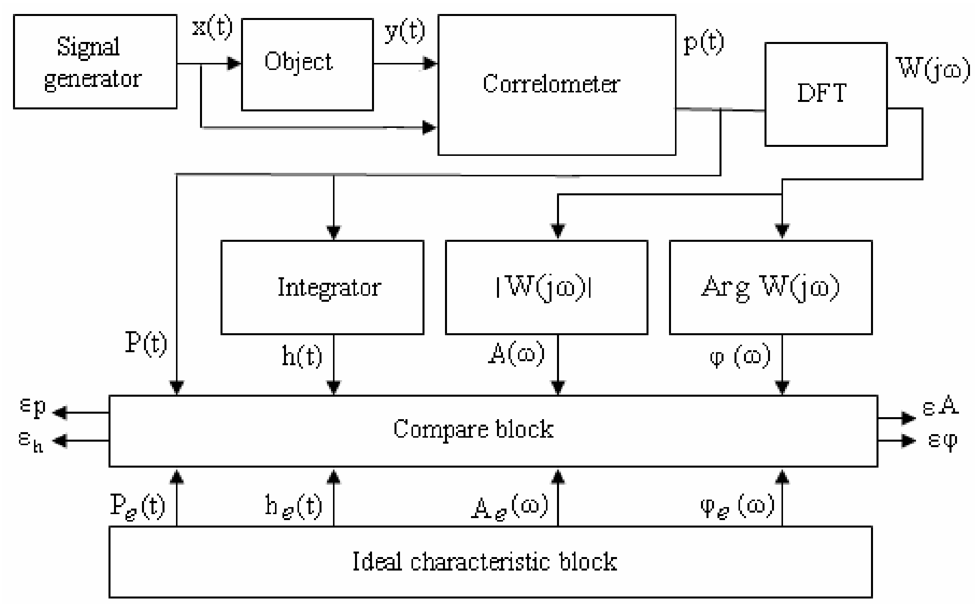

Fig. 1. Block-diagram of correlation measuring method
Rys. 1. Schemat blokowy metody korelacji pomiarowej

$$A(\omega)=k_1/\sqrt{\left(1-T_1^2\omega^2\right)^2+4\xi^2T_1^2\omega^2} \tag{9}$$

$$\varphi(\omega)=-arctg\left[2\xi T_1\omega/\left(1-T_1^2\omega^2\right)\right] \tag{10}$$

Measurements of these characteristics were carried out with and without Gaussian noise applied to the object output signal. The measuring method accuracy was determined as a root-mean-square deviation Y between the measured and analytically defined characteristics. The window of developed computer program for investigation of correlation method accuracy is shown in Fig.2. The program allows user to choose the type of the object characteristic from the menu and to set the mode of measurements – with or without noise, to set signal/noise relation values interval $[\min,\max]$ and measurement sessions quantity.

The following values of object parameters were taken to carry out the simulation: amplification coefficient $k_1=1$; decrement factor $q=0,4$; time constant $T_1=1/(2\pi)$ causing the tracking frequency close to resonance one $F_1=1$. The ratio of signal to noise V was taken in a range from 100 up to 10000 that corresponds to 20 … 40 dB. Measurement sessions quantity q for each signal was taken equal 1000. Observation interval was chosen equal to $524T$, where T - sampling interval. Pulse testing signal $\delta(t)$ was set during discrimination interval in a form

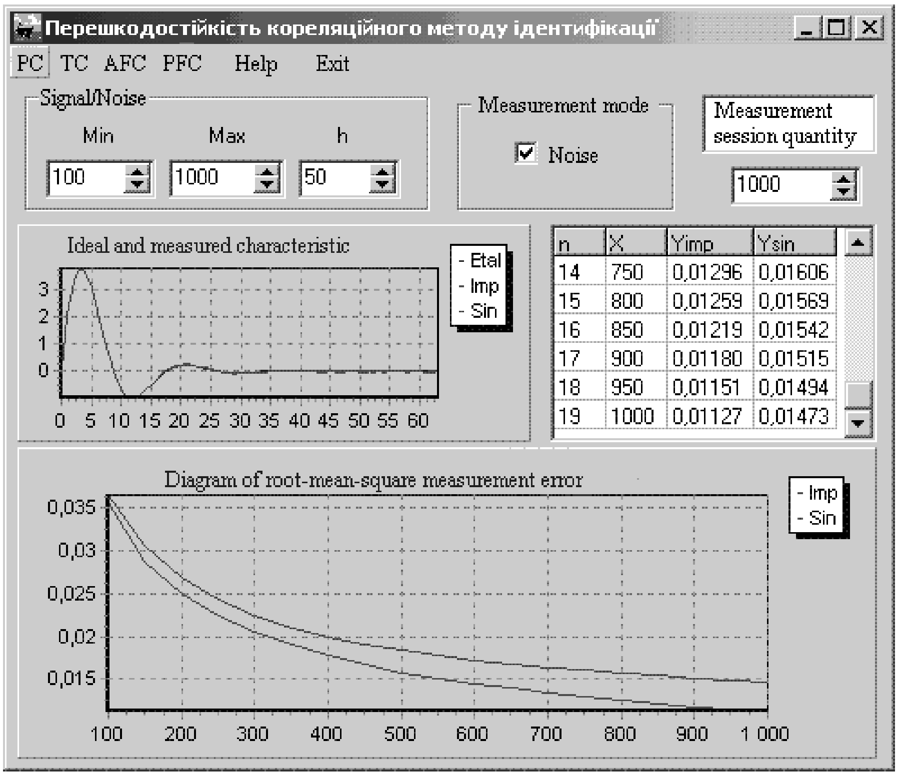

Fig. 2. The program window for correlation method accuracy investigation
Rys. 2. Okno programu do nadzoru dokładności metody korelacji

$$y(nT) = \begin{cases} \dfrac{\sin(n\frac{\pi}{2})}{n\frac{\pi}{2}}, & n \neq 0 \\ 0, & n = 0 \end{cases} \tag{11}$$

In this case each sinusoid half-cycle corresponded to one sampling interval T and the main petal duration of the signal $\sin(t)/t$ was equal $2T$. Total duration of the signal was taken equal to $64T$ and sampling rate F – 16 Hz. Values of methodical measuring error for two types of test signal in absence of noise were presented in table 1.One can see that errors for the pulse testing signal ($\delta(t)$) were a little bit smaller then for the $\sin(t)/t$ - signal.

Table 1

Methodical errors of oscillatory cell characteristics measurements for two types of test signal

Signal	PC	TC	AFC	PFC
δ-pulse	0,0000	0,0024	0,0115	0,0246
$\sin(t)/t$	0,0066	0,0025	0,0160	0,0330

The results of comparative investigations of correlation method accuracy with two types of test signals ($\sin(t)/t$ and $\delta(t)$) at the presence of noise are presented in Fig.3.

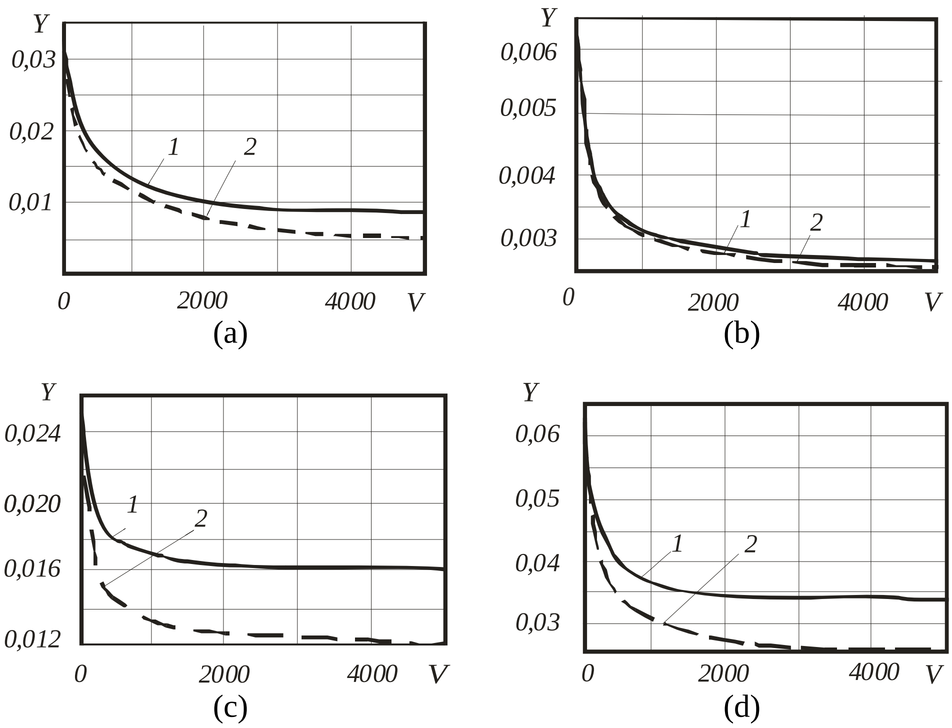

Fig. 3. The dependences of measuring error Y on signal/noise ratio V for the PC (a), TC (b), AFC (c) and PFC (d) with test signal $\sin(t)/t$ (1) and $\delta(t)$ (2)

Rys. 3. Zależność błędów pomiarowych Y od współczynnika poziomu sygnału do szumu V dla PC (a), TC (b), AFC (c) i PFC (d) z sygnałem testowym $\sin(t)/t$ (1) i $\delta(t)$ (2)

The errors of characteristics measurements Y were decreased with increasing of signal/noise ratio in a range of values V from 100 to 100000 gradually approximated to their methodical errors.

For the $V > 5000..7000$ values of error were changed very slightly; the dependences $Y(V)$ in Fig.3 were shown only for $V \le 5000$.

From results obtained one can see that error of system characteristic measurements of line objects in a voice frequency range at the noise presence by correlation method with $\delta(t)$ test signal was smaller than with $\sin(t)/t$ signal for all types of characteristics.

But differences between values of measurement error for pulse and transient characteristics for two types of testing signal were small enough, whereas for amplitude-frequency and phase-frequency characteristics differences were greater (up to 25 %). The errors of characteristic measurements Y were decreased with the increase in signal/noise ratio from 100 up to 100000 gradually approximated to their methodical errors.

3. CONCLUSION

Based on the developed computer simulation program the comparative investigations of accuracy of object characteristics measurements by correlation method in a voice-frequency range with two types of test signals $\sin(t)/t$ and $\delta(t)$ at a presence of a Gaussian noise in telecommunication lines were provided. In the absence of noise the methodical errors of correlation method with two types of testing signal are small. Maximum value of error was equal 3.3 10^{-2} for the phase-frequency characteristic measured with $\sin(t)/t$ test signal. The value of measuring error for $\delta(t)$ test signal was smaller than for $\sin(t)/t$ signal as at the presence or absence of a noise in a line.

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