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ALGORITHMIC METHODS FOR INCREASING THE METROLOGICAL CHARACTERISTICS OF INFORMATION-MEASURING SYSTEMS

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Abstract

Algorithmic methods for eliminating interference that affect the accuracy of measuring input signals in measuring channels are considered. Methods for input and processing of signals in the form of currents and voltages in analog modules of measuring channels of the control system are presented. It also considers some ways to improve the classical algorithms of adaptive control implemented on the basis of digital technology, taking into account the conditions for ensuring the stability of a discrete control system.

Keywords: *amplifiers, dividers, analog-pulse converters, microprocessor, analog noise, flicker noise, quantization noise, quantization errors, digital filters*.

1. Introduction

Metrological characteristics are an indicator of the quality of IMS, which determine the accuracy, reliability of information and their noise immunity over time within the established specified operating modes of control and process control systems.

In modern systems, various topologies, levels and methods of interrogating the measuring data module are used. The used data input-output modules are equipped with built-in microprocessors that perform a program poll of channels in accordance with the algorithm of the functioning of the servicing system for all active channels.

The greatest influence on the metrological characteristics of MI and, in particular, IMS is exerted by analog blocks that convert and normalize primary measurement information (for example, amplifiers, dividers, analog-pulse converters, etc.), that is, analog blocks that are part of the measuring channel materials[1].

2. Main part

Trends in the development of devices for analog input of information determine the following structure of the measuring channel (figure 1). A physical quantity (FQ) is converted by a primary measuring transducer (PMT) into current or voltage, then this signal is amplified by a unifying transducer (UT) to transmit this signal to the ADC inputs. Before the ADC, analog filters (AF) are usually installed. After the ADC, information signals in digital form are processed by a microprocessor (MP). The results of the measured parameter are transmitted via the interface channel to the control and monitoring systems(CMS)[2].

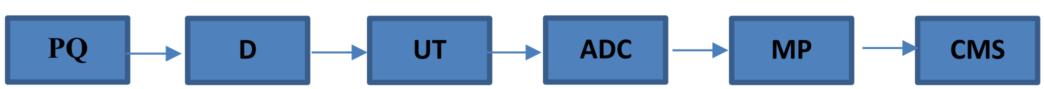

Figure 1. Structural diagram of the measuring channel.

The term resolution in measuring systems is usually understood as the current values of spurious signals and noise levels, against which it is necessary to isolate the useful signal. The level of signals at the output of precision sensors, as a rule, is insignificant and is in the range of 1.0 ... 30.0 mV. In order to amplify useful signals in the measuring, control system (analogue part), special circuit, technological solutions are used, in which their own noises have low values. Such technological solutions usually involve amplifiers (classic, instrumental), capacitors, resistive elements, analog-to-digital converters that have their own noise, and in addition, a power source, which is also an additional source for all elements in the circuit[3].

The intrinsic noise of the ADC is expressed as: noise appearing during quantization; analog noise; some non-linear random deviation. For example, quantization noise is defined by:

$$U_{\mathrm{N(qt)}} = \frac{\sqrt{\frac{1}{100}\frac{2 \cdot B}{f_{\mathrm{D}}}(1+DNL)}}{\sqrt{12}} \tag{1}$$

Analog Noise - RMS from thermal noise, shot noise, flicker noise, avalanche noise, and impulse noise. Analog noise in A/D converters is typically displayed as switching noise between adjacent codes.

Since the previously described noises do not have a correlation with each other, then to obtain their total value, the formula is used[4]:

$$U_N = \sqrt{\sum_{i=1}^{n} U_{Ni}^2} \tag{2}$$

The use of circuit solutions to improve the classical algorithms of adaptive control implemented on the basis of digital technology, taking into account the conditions for ensuring the stability of a discrete control system, does not always give the desired result.

Further development of control systems for technical processes is based on the intellectualization of automatic control systems using modern methods and technologies for knowledge processing[5].

At the same time, the actual question arises of creating a new element base - neural network structures, fuzzy controllers focused on supporting intelligent information processing and control technologies.

For example, in the classical concept, to develop a system that implements digital filtering algorithms, various circuit solutions were used: digital control devices, operational amplifiers with a different set of frequency characteristics and signal conversion coefficients.

A digital filter (DF) can be considered as a discrete system described by the equation below, the solution of which is carried out by software.

$$y(nT) =-\sum_{m=1}^{M-1} a_m y(nT-mT)+\sum_{k=0}^{N-1} b_x x(nT-kT) \tag{3}$$

When a signal (sequence) $x(nT)$ is applied to a digital filter having an impulse response $h(nT)$, then based on (3) the output signal $y(nT)$ can be calculated by the formula[6]:

$$y(nT)=\sum_{k=0}^{N-1} h(kT)x(nT-kT), \tag{4}$$

or for the general case

$$y(nT)=\sum_{k=0}^{\infty} h(kT)x(nT-kT), \tag{5}$$

In this case, $h(kT)\to 0$ for $k\to\infty$.

As a result of signal quantization at the input, quantization noises are certain errors of a periodic nature $e_{in}(nT)$ that affect the input signal and affect the quality of digital filtering. If we take the digital filter as a linear one, that is, all operations of the filter coefficients in the processor are implemented exactly, it is possible to calculate the behavior of the filter $e_{out}(nT)$ on input noise[7]:

$$\mathrm{e}_{out}(nT)=\sum_{k=0}^{N-1} h(kT)\mathrm{e}_{in}(nT-kT)\ for\ N\le\infty. \tag{6}$$

In the same way, it is possible to calculate signal errors at any points in the block diagram in a discrete (linear) filter, which appears due to quantization noise on the input signal $e_{in}(nT)$. For example, $h_i(nT)$ is the impulse response of the filter element, then in this case, the errors of the signals at the output of the adder,

$$\mathrm{e}_i(nT)=\sum_{k=0}^{\infty} h_i(kT)\mathrm{e}_{in}(nT-kT). \tag{7}$$

In a situation where the bit depth of samples on the input signal after the decimal point is equal to b_{in}, then the quantization error (with rounding) on the input signal will have a number limit[8]:

$$\mathrm{E}_{in}=\max_n\left|\mathrm{e}_{in}(nT)\right|=2^{-b_{in}-1}=Q_{in}/2 \tag{8}$$

and estimate the quantization error of the output signals

$$\mathrm{E_{out}}=\max_n\left|\mathrm{e_{out}}(nT)\right|\le\max_n\left|\mathrm{e_{out}}(nT)\right|\sum_{k=0}^{\infty}|h(kT)|\le\frac{Q_{\mathrm{in}}}{2}\sum_{k=0}^{\infty}|h(kT)|. \tag{9}$$

An estimate is also made for $e_{in}(nT)$. Therefore, the upper level of the quantization error of the output signals depends on the summation of the modules of the signal samples, based on its impulse parameters[9].

The variance of the input noise is defined as follows - $\sigma_{in}^2 = \frac{1}{12} 2^{-2b_{in}} = Q_{in}^2/12$, then the variance of the quantization noise $e_{out}(nT)$, which is at the output in the filter,

$$\sigma_{out}^2 = \sigma_{in}^2 \sum_{k=0}^{N-1} h^2(kT) \tag{10}$$

and in the general situation, taking into account that for stable filters $h(nT) \to 0$ as $n \to \infty$,

$$\sigma_{\text{out}}^2 = \sigma_{\text{in}}^2 \sum_{k=0}^{\infty} h^2(kT) = \frac{Q_{\text{inвх}}^2}{2} \sum_0^{\infty} h^2(kT). \tag{11}$$

Based on Parseval's equality

$$\sum_{k=0}^{\infty} h^2(kT) = \frac{T}{\pi} \int_0^{\frac{\pi}{T}} |H(e^{j\omega T})|^2 d\omega \tag{12}$$

It is possible to write (10) and how

$$\sigma_{\text{out}}^2 = \sigma_{\text{in}}^2 \frac{\text{T}}{\pi} \int_0^{\frac{\pi}{T}} |H(e^{j\omega T})|^2 d\omega \ , \tag{13}$$

where $|H(e^{j\omega T})|$- frequency response for the digital filter.

Therefore, according to the possible level σ_{out}^2 and the known amplitude-frequency characteristic or IR of such a digital filter, it is possible to identify the permissible level of error dispersion for input signals σ_{in}^2, which has a direct dependence on the bit depth b of the numbers that are samples of the input signals[10].

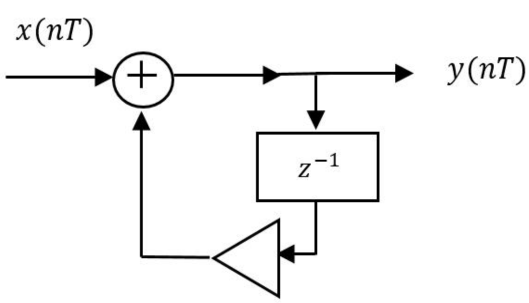

Figure 2. Digital filters of the $n1^{th}$ order.

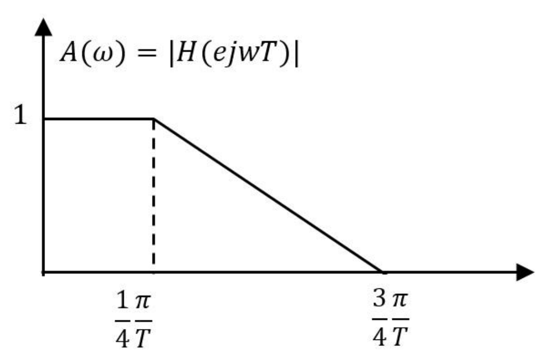

Figure 3. Frequency response NCF.

Digital filters of the 1st order (figure 2) can be described using the difference equation $(nT) = x(nT) + ay(nT - T)$. The quantization noise of the input signals has a dispersion σ_{in}^2. We are looking for the dispersion of the output noise $\sigma_{in_{BX}}^2$ and indicate at what level of the filter parameters α the input noise can be amplified by the filter.

Based on (8)

$$\sigma_{out}^2 = \sigma_{in}^2 \sum_{n=0}^{\infty} a^{2n} = \sigma_{in}^2[1/(1-a^2)]. \tag{14}$$

In order to ensure the stability of the filter, it is necessary $||a| < 1, a^2 < 1$ and, accordingly, $\sigma_{out}^2 > \sigma_{in_{BX}}^2$, the more $|a|$ tends to 1, the more the input noise level will increase filter[11].

In figure 3 the amplitude-frequency characteristic of the NCF is demonstrated. Calculate the level of noise dispersion at the output stages σ_{out}^2, which appears due to the quantization of input signals, if the value of σ_{in}^2 is known, based on (10)

$$\sigma_{out}^2 = \frac{T}{\pi}\sigma_{in}^2\left(\int_0^{\frac{\pi}{4T}} 1d\omega + \int_{\frac{\pi}{4T}}^{\frac{3\pi}{4T}}\left(1{,}5 - \frac{2T}{\pi}\omega\right)^2 d\omega\right) = 0{,}417\sigma_{in}^2. \tag{15}$$

It should be noted that the level of noise dispersion $e_{out}(nT)$, which appear due to the quantization of input signals, can be found from the formula

$$\sigma_{\text{out}}^2 = \frac{\text{T}}{\pi}\int_0^{\frac{\pi}{T}}\left|S_{\text{out}}\left(\text{e}^{j\omega T}\right)\right|d\omega\ , \tag{16}$$

Where $S_{out}(e^{j\omega T}) = S_{in}(e^{j\omega T})\left|H(e^{j\omega T})\right|^2$, $S_{out}(e^{j\omega T})$ and $S_{in}(e^{j\omega T})$- according to the levels of power spectral densities for the output and input signals[12].

Let us find the level of output quantization noise, which appears due to the rounding off of products in the first-order stable element $|a| < 1$, the block diagram of which is shown in figure 4. To do this, it is necessary to create a model, taking into account the source of the product quantization noise (figure 4). From this model, you can see that the quantization errors will go through the same circuits as the pulse and input signals. characteristics that correspond to noise sources will coincide with the impulse parameters in the entire filter and, accordingly,

$$\sigma_{out}^2 = \sigma_r^2 \sum_{n=0}^{\infty} h^2(nt) = \frac{Q^2}{12}\sum_{n=0}^{\infty} a^{2n} = \frac{Q^2}{12}\frac{1}{1-a^2} \tag{17}$$

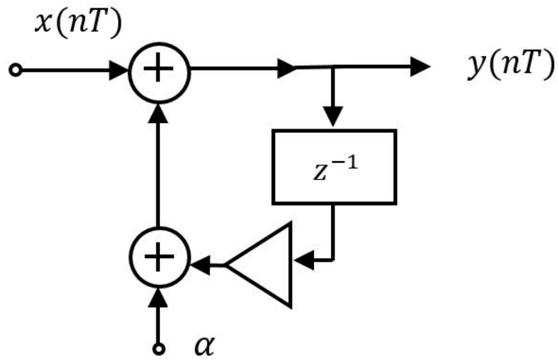

Figure 4. Block diagram of output quantization noise.

Let us find the quantization noise of the order, the general structural scheme of which is shown, taking into account the sources of quantization noise $e_1(nT)$ and $e_2(nT)$ will pass through the same chains, so that the parameters for them will coincide with *and*; chains of passage of input signals and pulse[13].

$$\sigma^2_{r.out} = (\sigma^2_{e1} + \sigma^2_{e2}) \sum_{n=0}^{\infty} h^2(nt) . \tag{18}$$

As a result, we can conclude that the level of common quantization errors that appear due to quantization of input signals and quantization of the results of a number of results of operations of an arithmetic type can be found through the sum of the estimation of the corresponding error.

3. Conclusion

As a result, we can conclude that the level of common quantization errors that appear due to quantization of input signals and quantization of the results of a number of results of operations of an arithmetic type can be found through the sum of the estimation of the corresponding error.

Further improvement of classical adaptive control algorithms implemented on the basis of digital technology, taking into account the conditions for ensuring the stability of a discrete control system, is based on the intellectualization of automatic control systems using a new element base - neural network structures, fuzzy controllers focused on supporting intelligent information processing and control technologies.

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