Investigation of Measurement Errors of Electrical Signals Characteristics of Energy Supply Systems

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Abstract

The study substantiates the current scientific and technical problem of developing precision methods for measuring the parameters of electrical signals (usually harmonic voltages), which will allow to create a fairly simple control equipment with desired characteristics. The method of measuring the frequency (period) of a sinusoidal signal based on the conversion of voltage into the frequency of pulses is investigated. This method has pronounced filtering properties with respect to interference. In particular, if the interference is harmonic with a frequency multiple of the frequency of the measured signal, the error caused by interference is virtually absent. The method of measuring phase shift with intermediate voltage-frequency conversion is investigated. This method eliminates the dependence of the measurement result on the frequency of the studied signals. This expands the frequency range and increases accuracy. Also, this method has a short measurement time, no more than one or two periods of the studied signals, which is especially important when measuring infrared frequency signals. The method of power measurement with intermediate voltage-frequency conversion is investigated. This method reduces the power measurement error with increasing broadband interference.

Keywords

Error, electrical signal, power supply system, method, obstacle

1. Introduction

Increasing the requirements for electricity quality indicators of energy supply systems of water transport vehicles requires improvement of methods and means of their control [1, 2]. However, the further development of such measuring instruments is largely constrained by the level of their technical characteristics (errors in measuring electricity quality indicators) at low cost. Today it is not economically necessary to use high-precision control equipment on water vehicles, which is constantly in harsh operating conditions [3, 4]. Therefore, a very important scientific and technical task is to develop precise methods for measuring the parameters of electrical signals (usually harmonic voltages), which will create a fairly simple and at the same time with the desired characteristics of the control equipment

In this regard, there is an urgent scientific and technical problem in the field of monitoring the technical condition of energy supply systems of water transport: improving methods of synthesis of equipment for monitoring the technical condition of energy supply systems of water transport by reducing their errors in measuring the characteristics of electrical signals.

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2. Investigation of measurement errors of electrical signals characteristics

2.1. Literature analysis

A significant number of publications are devoted to the problem of monitoring the technical condition of power supply systems of various technical systems [5 - 17].

Thus, the article [5] considers the method of monitoring the technical condition of electronic circuits that are part of power supply systems. In [6 - 9] the results of research of methods of synthesis of the equipment of control of a technical condition of radio electronic systems of water transport vehicles are presented. However, in such works the estimation of errors of measurement of parameters of the electronic equipment at control of a technical condition is not resulted.

In the publications [10 - 14] the questions of functioning of modern electric and electronic systems are considered, the factors which essentially influence definition of their technical condition are allocated.

In [15 - 17] the results of efficiency of technical condition control of a power supply systems at operation of water transport vehicles and in the field of development of the digital control equipment are presented. However, in such works there are no results of research of influence of features of operation of the control equipment in the aggressive environment (sea and river environment) on an error of measurement of electric signals characteristics at control of a technical condition.

Thus, the most critical for the synthesis of equipment for monitoring the technical condition of energy supply systems of water transport are: the lack of results of estimation errors in measuring the characteristics of electrical signals; lack of results of evaluation of the influence of interference on the measurement error of the characteristics of electrical signals; lack of a reasonable universal method for measuring the characteristics of electrical signals with minimal errors under interference.

The results of the analysis of modern literature show the lack of universal methods for the synthesis of equipment for monitoring the technical condition of energy supply systems of water transport to ensure minimal errors in measuring the characteristics of electrical signals. Therefore, the topic of the article, aimed at studying the errors in measuring the characteristics of the electrical signal of the power supply systems of water transport vehicles, is relevant.

2.2. Frequency measurement method with intermediate voltage-frequency conversion

The method of measuring the frequency (period) of a sinusoidal signal based on the conversion of voltage into pulse frequency is as follows.

Let the signal under study be described by an expression

$$u(t) = v_m \sin \omega t + \xi(t), \quad (1)$$

where V_m is the amplitude of the measured signal;

ω is circular frequency of the studied signal;

$\xi(t)$ is stationary interference that is present in the input signal.

This signal will be converted into a proportional pulse frequency

$$f(t) = K_f v_m \sin \omega t + K_f \xi(t), \quad (2)$$

where K_f is voltage to frequency conversion factor.

Frequency-modulation pulse $f(t)$ the signal is integrated at intervals equal to the half-cycle of the input signal, where the number of output impulses:

$$N_T = \int_0^{T/2} f(t)dt\,. \quad (3)$$

Substituting the ratio (2) in the formula (3), we find

$$N_T = K_f v_m \int_0^{\frac{T}{2}} [\sin\omega t + \xi(t)]dt =$$
$$= K_f V_m \int_0^{\frac{T}{2}} \sin \omega t dt + K_f \int_0^{\frac{T}{2}} \xi(t)dt = \quad (4)$$
$$\frac{K_f V_m T}{\pi} + \Delta N_\xi = N_T + \Delta N_\xi,$$

where $N_T = \dfrac{K_f V_m T}{\pi}$ is informative, useful component of the measurement result, proportional to the period T of the signal $u(t)$;

$\Delta N_{\xi} = K_f \int_0^{\frac{\pi}{2}} \xi(t)dt$ is error introduced by the obstacle.

Taking into account only the useful component of the measurement result, we write

$$T = \frac{N_T \pi}{K_f V_m} = \frac{K_T}{V_m} N_T\,, \qquad (5)$$

where $K_T = \frac{\pi}{K_f}$ is coefficient of proportionality.

The frequency of the studied signal will be determined from the ratio

$$f = \frac{1}{T} = \frac{V_m}{K_T N_T} = \frac{K_f V_m}{N_T} \qquad (6)$$

where $K_f = \frac{1}{K_T}$.

As can be seen from ratio (6) the result of frequency measurement f depends on the amplitude V_m of harmonic signal. To eliminate this dependence, the studied signal can be subjected to amplitude normalization, ie to achieve V_m= const.

Then expression (6) can be written as

$$f = \frac{d_f}{N_T}\,, \qquad (7)$$

where $d_f = K_f V_m$ is discreteness of frequency measurement.

For error analysis ΔN_{ξ}, introduced by interference, fully applied estimates that the averaging algorithm has pronounced filtering properties with respect to interference. In particular, if the interference is harmonic with a frequency multiple of the frequency of the measured signal, then error $\Delta N_{\xi} = 0$.

2.3. Method of measuring phase shift with intermediate voltage-frequency conversion

Suppose it is necessary to measure the phase shift between two sinusoidal signals described by expressions

$$\begin{aligned} u_1(t) &= V_{1m} \sin \omega t; \\ u_2(t) &= V_{2m} \sin(\omega t - \varphi), \end{aligned} \qquad (8)$$

where V_{1m}, V_{2m} is the amplitude of the measured signals;

ω is circular frequency of the studied signal;

φ is measured phase shift.

The algorithm for measuring the phase shift is as follows:

a) one of the input signals, for example $u_2(t)$, should be differentiated

$$u_3(t) = \frac{\partial U_2(T)}{\partial t} = K_{\partial} V_{2m} \omega \cos(\omega t - \varphi)\,, \qquad (9)$$

where K_{∂} is the transmission factor of the differentiation unit;

b) received signal $V_3(t)$ will become proportional to the frequency of the pulses

$$f(t) = K_f u_3(t) = K_f K_{\partial} V_{2m} \omega \cos(\omega t - \varphi); \qquad (10)$$

c) frequency pulses $f(t)$ are counted (integrated) twice:

– once for the time interval between voltage transitions $u_1(t)$ and $u_2(t)$ through zero;

– another time during the time interval between voltage transitions $u_2(t)$ through zero and maximum;

$$\begin{aligned} N_1 &= \frac{1}{\omega} \int_0^{\varphi} f(t) d(\omega t) = \\ &= K_f K_{\partial} V_{2m} \int_0^{\varphi} \cos(\omega t - \varphi) d(\omega t) = \\ &= K_f K_{\partial} V_{2m} \sin \varphi, \end{aligned} \qquad (11)$$

$$\begin{aligned} N_2 &= \frac{1}{\omega} \int_{\varphi}^{\frac{\pi}{2}+\varphi} f(t) d(\omega t) = \\ &= K_f K_{\partial} V_{2m} \int_{\varphi}^{\frac{\pi}{2}+\varphi} \cos(\omega t - \varphi) d(\omega t) = \\ &= K_f K_{\partial} V_{2m}; \end{aligned} \qquad (12)$$

d) phase shift measurement φ will be determined from the following expression

$$\varphi = \arcsin \frac{N_1}{N_2}. \qquad (13)$$

The considered method of phase shift measurement has the following advantages.

First, it eliminates the dependence of the measurement result (13) on the frequency of the studied signals, which ultimately leads to an expansion of the frequency range and increase accuracy, because the effect of instability of the frequency of the measured signals is eliminated. The measurement result also does not depend on the amplitude of the studied signals.

Secondly, it has a short measurement time, no more than one or two periods of the studied signals, which is especially important when measuring infrared frequency signals.

Another variant of the method of measuring the phase shift with intermediate voltage-frequency conversion is possible. In it, the signal module is subjected to frequency conversion $u_2(t)$:

$$\mid u_2(t) \mid = V_{2m} \mid sin(\omega t - \varphi) \mid, \qquad (14)$$

$$f(t) = K_f \, V_{2m} \mid sin(\omega t - \varphi) \mid. \qquad (15)$$

Expression (15) will be integrated twice: in the interval from $(\frac{\pi}{2} + \varphi)$ to π

$$N_1 = \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi}^{\pi} f(t) d(\omega t) =$$

$$= \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi}^{\pi} K_f V_{2m} \left| sin(\omega t - \varphi) \right| d(\omega t) = \qquad (16)$$

$$= \frac{K_f V_{2m}}{\omega} cos\varphi;$$

is at intervals from $(\frac{\pi}{2} + \varphi)$ to $(\pi + \varphi)$

$$N_2 = \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi}^{\pi+\varphi} f(t) d(\omega t) =$$

$$= \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi}^{\pi+\varphi} K_f V_{2m} \left| sin(\omega t - \varphi) \right| d(\omega t) = \qquad (17)$$

$$= \frac{K_f V_{2m}}{\omega}.$$

In this case, the measurement result is found by the formula

$$\varphi = arccos N, \qquad (18)$$

where $N = N_1 / N_2$.

In addition to the instrumental error of voltage-frequency conversion, one of the dominant errors of this method of measuring phase shifts is the error due to the inaccuracy of the formation of time intervals during which the frequency integration $f(t)$ and the formation of intermediate results N_1 i N_2. Let's estimate this error.

Denote by $\Delta\varphi_1$, $\Delta\varphi_2$ i $\Delta\varphi_3$ phase errors of selection of the moments corresponding to phases:

$$\omega t_1 = \frac{\pi}{2} + \varphi; \quad \omega t_2 = \pi; \quad \omega t_3 = \pi + \varphi.$$

Given the error $\Delta\varphi_1$ i $\Delta\varphi_2$ from expression (16) we find

$$N_1 = \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi+\Delta\varphi_1}^{\pi+\Delta\varphi_2} f(t) d(\omega t) = \frac{K_f V_{2m}}{\omega} \times$$

$$\times \int_{\frac{\pi}{2}+\varphi+\Delta\varphi_1}^{\pi+\Delta\varphi_2} sin(\omega t - \varphi) d(\omega t) = \frac{K_f V_{2m}}{\omega} \times \qquad (19)$$

$$\times (cos\varphi cos\Delta\varphi_2 + sin\varphi sin\Delta\varphi_2 - sin\Delta\varphi_1).$$

Given that errors $\Delta\varphi_1$, $\Delta\varphi_2$ and $\Delta\varphi_3$ low, we have

$$cos\Delta\varphi_2 \approx 1; \; sin\Delta\varphi_1 \approx \Delta\varphi_1; \qquad (20)$$
$$sin\Delta\varphi_2 \approx \Delta\varphi_2.$$

Then expression (19) takes the form

$$N_1 = N_1 - \frac{K_f V_{2m}}{\omega} (\Delta\varphi_1 + \Delta\varphi_2 \, sin\varphi). \qquad (21)$$

Similarly, from expression (17) we obtain

$$N_2 = \frac{1}{\omega} \int_{\frac{\pi}{2}+\varphi+\Delta\varphi_1}^{\pi+\varphi+\Delta\varphi_3} f(t) d(\omega t) =$$

$$\frac{K_f V_{2m}}{\omega} \int_{\frac{\pi}{2}+\varphi+\Delta\varphi_1}^{\pi+\varphi+\Delta\varphi_3} sin(\omega t - \varphi) d(\omega t) =$$

$$= \frac{K_f V_{2m}}{\omega} (cos\Delta\varphi_3 - sin\Delta\varphi_1) \approx \qquad (22)$$

$$\approx N_2 - \frac{K_f V_{2m}}{\omega} \Delta\varphi_1.$$

From relations (21) and (22) we find the absolute measurement errors

$$\Delta N_1 = N_1 - N = -\frac{K_f V_{2m}}{\omega} (\Delta\varphi_1 + \Delta\varphi_2 \, sin\varphi)$$
;

$$\Delta N_2 = N_2 - N_2 = -\frac{K_f V_{2m}}{\omega} \Delta\varphi_1. \qquad (23)$$

Thinking $\left|\Delta\varphi_1\right| = \left|\Delta\varphi_2\right| = \Delta\varphi_{max} = \Delta\varphi$, we obtain the error limits

$$\Delta N_{1m} = \frac{K_f V_{2m}}{\omega} \Delta\varphi_1 (1 + sin\varphi); \qquad (24)$$

$$\Delta N_{2m} = \frac{K_f V_{2m}}{\omega} \Delta\varphi. \qquad (25)$$

Limits of change of absolute errors in measurement of sizes N_1 and N_2:

$$\frac{K_f V_{2m}}{\omega}\Delta\varphi \le \Delta N_1 \le \frac{K_f V_{2m}}{\omega}2\Delta\varphi . \qquad (26)$$

$$\Delta N_2 \le \frac{K_f V_{2m}}{\omega}\Delta\varphi . \qquad (27)$$

Using expressions (19) and (22), we find the absolute error of definition $cos\,\varphi$:

$$\Delta N = \frac{N_1}{N_2} - \frac{N_1}{N_2} =$$

$$= \frac{cos\,\Delta\varphi_2\, cos\,\varphi + sin\,\Delta\varphi_2\, sin\,\Delta\varphi - sin\,\varphi_1}{cos\,\Delta\varphi_3 - sin\,\Delta\varphi_1} - cos\,\varphi =$$

$$= \frac{\begin{pmatrix} cos\,\Delta\varphi_2\, cos\,\varphi + sin\,\Delta\varphi_2\, sin\,\Delta\varphi - sin\,\varphi_1 - \\ - cos\,\Delta\varphi_3\, cos\,\varphi + sin\,\Delta\varphi_1 \end{pmatrix}}{cos\,\Delta\varphi_3 - sin\,\Delta\varphi_1} .$$

Taking into account equations (20) we obtain

$$\Delta N \approx \frac{sin\,\Delta\varphi cos\,\varphi + sin\,\Delta\varphi sin\,\varphi - sin\,\varphi}{cos\,\Delta\varphi - sin\,\Delta\varphi} = \qquad (28)$$

$$= \frac{\Delta\varphi}{1-\Delta\varphi}(cos\,\varphi + sin\,\varphi - 1).$$

The component error of phase shift measurement introduced by the inaccuracy of the integration intervals is found from expression (18)

$$\Delta\varphi = \frac{\partial\varphi}{\partial N}\Delta N = \frac{\Delta N}{\sqrt{1-N^2}} , \qquad (29)$$

where ΔN is determined from the ratio (28)

2.4. Power measurement method with intermediate voltage-frequency conversion

The essence of the method consists in converting the voltage proportional to the instantaneous power into the pulse frequency, which is then integrated over a certain time interval, depending on the type of measured value – active, reactive or full power.

Let the voltage and current in the investigated circuit be determined by the expression

$$u(t) = U_m\, sin\,\omega t ,\ i(t) = I_m\, sin(\omega t - \varphi) .$$

By signals $u(t)$ and $i(t)$ a voltage proportional to their product is formed

$$u_1(t) = K_M u(t) i(t) = \qquad (30)$$

$$= K_M UI\left[cos\,\varphi - cos(2\omega t - \varphi)\right],$$

where K_M is the transfer factor of the multiple block;

U, I is rms value according to voltage and current.

From the signal $u_1(t)$ the variable component is allocated

$$u(t) = -K_M UI\, cos(2\omega t - \varphi), \qquad (31)$$

and its module with the help of a voltage-frequency converter will be converted into a pulse frequency

$$f(t) = K_M UI\left|cos(2\omega t - \varphi)\right| . \qquad (32)$$

Depending on the type of measured power signal $f(t)$ integrates over a period of time.

When measuring active power, the time interval of integration or frequency averaging $f(t)$ concluded between $t_{\varphi/2}$ and $T/8$, which is equal to the phase interval from $\varphi/2$ to $\pi/4$. Integrating frequency $f(t)$ within the given limits, we find:

$$N_1 = \frac{1}{\omega}\int_{\varphi/2}^{\pi/4} f(t) d(\omega t) = K_f K_M UI \frac{1}{\omega} \times$$

$$\times \int_{\varphi/2}^{\pi/4} \left|cos(2\omega t - \varphi)\right| d(\omega t) = \qquad (33)$$

$$= \frac{K_f K_M T}{2\pi} UI\, cos\,\varphi = K \cdot T \cdot P ,$$

where $P = UI\, cos\,\varphi$ is measured active power of the circuit;

$K = \frac{K_f K_M}{2\pi}$ is coefficient of proportionality.

When measuring the reactive power, the frequency integration is carried out in the time interval from 0 to $t_{\varphi/2}$ or in the phase range from 0 to $\varphi/2$:

$$N_2 = \frac{1}{\omega}\int_{0}^{\varphi/2} f(t) dt\omega t = K_f K_M UI \frac{1}{\omega} \times$$

$$\times \int_{0}^{\varphi/2} \left|cos(2\omega t - \varphi)\right| d(\omega t) = \qquad (34)$$

$$= \frac{K_f K_M}{2\pi} TUI\, sin\,\varphi = K \cdot T \cdot Q,$$

where $Q = UI\, sin\,\varphi$ is measured reactive power.

In the mode of measurement of full power averaging is conducted in a time interval from $t_{\varphi/2}$ до $t_{\varphi/2} + T/8$ or in the phase range from $\varphi/2$ до $(\varphi/2) + \pi/4$:

$$N_3 = \frac{1}{\omega} \int_{\varphi/2}^{\varphi/2+\pi/4} f(t)d(\omega t) =$$

$$= K_f K_M UI \frac{1}{\omega} \int_{\varphi/2}^{\varphi/2+\pi/4} |cos(2\omega t - \varphi)| d(\omega t) = \quad (35)$$

$$= \frac{K_f K_M}{2\pi} TUI = K \cdot T \cdot S .$$

where $S = UI$ is full power in the studied circuit.

To eliminate the dependence of the power measurement results on the frequency (period) of the studied signals, it is necessary to convert the period of one of the signals into a code N, for example, by the method of discrete number. We will get $N = T/d_T$ or $T = d_T N_T$, where d_T is discreteness of period measurement. Substituting this equality in formulas (33), (34), (35), we get

$$N_p = K_9 \frac{N_1}{N_T} = KK_9 d_T P = P/\alpha_P , \quad (36)$$

$$N_Q = K_9 \frac{N_2}{N_T} = KK_9 d_T Q = Q/\alpha_P , \quad (37)$$

$$N_S = K_9 \frac{N_3}{N_T} = KK_9 d_T S = S/\alpha_P , \quad (38)$$

where $\alpha_P = \frac{2\pi}{K_F K_M K_9 d_T}$ is discreteness of power measurement;

K_9 is the transfer factor of the code divider.

2.5. Method for measuring the RMS value of the amplitude-modulated signal with intermediate voltage-frequency conversion

The expression for the amplitude-modulated (AM) signal is written as follows

$$u(t) = u_M(t) sin\,\omega t , \quad (39)$$

where $u_M(t)$ – signal enveloping or modulating the signal with a period T_M ;

$\omega = 2\pi f = \frac{2\pi}{T}$ is the circular frequency of the carrier, the initial phase of which is simplified to zero to simplify the records;

T, f is period and carrier frequency.

AM signal module

$$|\ u(t)\ | = U_M |\ sin\,\omega t\ | ,$$

convert to a proportional frequency of pulses

$$f(t) = K_f u_M(t) |sin\,\omega t| .$$

Frequency $f(t)$ we will integrate for the averaging interval equal to half of the q-th period of the carrier frequency, and obtain the number of pulses

$$N_q = \int_{t_q}^{t_q+\pi/2} f(t)dt = K_f \int_{t_q}^{t_q+\frac{\pi}{2}} u_M(t)|sin\,\omega t| dt . \quad (40)$$

Given that in the q-th half-cycle of the carrier $u_M(t_q) = V_q$ that is, has a strictly defined value equal to the amplitude of the carrier, we obtain

$$N_q = K_f V_q \int_{t_q}^{t_q+\pi/2} |sin\,\omega t| dt =$$

$$= K_f V_q \frac{2}{\omega} = \frac{K_f T}{\pi} V_q . \quad (41)$$

From expression (41) we find the amplitude of the carrier frequency in the q-th half-cycle of the AM signal

$$V_q = \frac{\pi}{K_f T} N_q = \frac{\pi f}{K_f} N_q . \quad (42)$$

Knowing the amplitude of the carrier, determine the root mean square value of the amplitude-modulated signal

$$V_{AM} = \sqrt{\frac{1}{n}\sum_{q=1}^{n} V_q^2} = \frac{\pi f}{K_f \sqrt{n}} \sqrt{\sum_{q=1}^{n} N_q^2} =$$

$$= K_{AM} \sqrt{\sum_{q=1}^{n} N_q^2} , \quad (43)$$

where $K_{AM} = \frac{\pi f}{K_f \sqrt{n}}$ is coefficient of proportionality,

$n = \frac{2T_M}{T}$ is the number of samples or codes, instantaneous values of the AM signal for the enveloping period.

The developed method of measuring the RMS value of the AM signal has a high noise immunity. Let's show it.

We present the investigated signal by the sum of the AM signal and the stationary interference

$$u(t) = u_M(t) sin\,\omega t + \xi(t) ,$$

where $\xi(t)$ is stationary interference that is present in the input signal.

Then to the result of measuring the value N_q, due to the relation (41) an error is introduced

$$N_q = \frac{\pi f}{K_f} N_q . \quad (44)$$

The variance of this error:

$$\left\langle (\Delta N_q)^2 \right\rangle = K_f^2 \int_{t_q}^{t_q+\frac{\pi}{2}} \int \left\langle \xi(t)\xi(t^{|}) \right\rangle dt dt^{|} =$$

$$= \mathrm{K}_f^2 \int_{t_q}^{t_q+\frac{\pi}{2}} \int \sigma_\xi^2 r(t-t^{|}) dt dt^{|} =$$

$$= \mathrm{K}_f^2 \sigma_\xi^2 \int_{t_q}^{t_q+\frac{\pi}{2}} \int r(t-t^{|}) dt dt^{|} = \quad (45)$$

$$= K_f^2 \sigma_\xi^2 \int_0^{\frac{T}{2}} r(t) dt = K_f^2 \sigma_\xi^2 \frac{T}{2} \tau_\xi ,$$

where σ_ξ^2 is interference dispersion;

$r(t-t^{|})$ is normalized correlation function, r(0)=1;

τ_ξ is interference correlation time.

The relative value of the error introduced by the obstacles when measuring the q-th value of the envelope:

$$\delta N_q = \frac{\sqrt{\left\langle (\Delta N_q)^2 \right\rangle}}{N_q} = \frac{\sigma_\xi}{V_q} \frac{\pi}{\sqrt{2}} \sqrt{\frac{\tau_\xi}{T}} = \quad (46)$$

$$= 2.22 \frac{\sigma_\xi}{V_q} \sqrt{\frac{\tau_\xi}{T}} .$$

From relation (46) it follows that the relative value of the error introduced by the interference, when measuring the q-th value of the amplitude of the envelope, will decrease with increasing broadband interference, ie when the condition $\tau_\xi \prec\prec T$.

3. Conclusions

When analyzing the error introduced by interference, when using the method of converting voltage (phase, power) into frequency when measuring electrical parameters, the estimates that characterize the averaging algorithm are fully applied, ie it has pronounced filtering properties with respect to interference. That means that this method is noise-proof.

The method of measuring phase shift with intermediate voltage-frequency conversion is presented. The considered method of phase shift measurement has the following advantages. It eliminates the dependence of the measurement result on the frequency of the studied signals, which ultimately leads to an expansion of the frequency range and increase accuracy, because the effect of instability of the frequency of the measured signals is eliminated. The measurement result also does not depend on the amplitude of the studied signals. Has a short measurement time, no more than one or two periods of the studied signals.

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