Compensatory Method for Measuring Phase Shift Using Signals Bisemiperiodic Conversion in Diagnostic Intelligence Systems

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Abstract

This article dwells upon phase shift determination method using total signal obtained as a result of summing up two harmonic signals after carrying out bisemiperiodic transformation, which can be attributed to measurement compensation method. Value of phase shift has been determined by comparing vector obtained after amplitude time analog-digital conversion of total signal with a set of reference function vectors. Maximum value of correlation coefficient has been used as criterion for specified vectors coincidence. Algorithm for finding the maximum correlation coefficient using golden section method has been developed. Main errors sources for proposed method of phase shift measurement have been determined. Application of proposed method in artificial intelligence system for diagnostic and determination of modern weapons and military equipment state will allow to reduce requirements for measuring equipment without reducing accuracy of measurements.

Keywords 1

Compensation method, phase shift, harmonic signal, measurement, diagnostics, phase shift measurement, measurement error, extremum, correlation coefficient

1. Introduction

Technological revolution in recent years has required radical changes in military industry. Implementation of new technologies in military sphere is impossible without computer use and telecommunication equipment, artificial intelligence technologies, military and medical robotics, etc.

Development of military equipment latest samples for the Ukraine forces, their adoption and control of technical condition during operation require the search for new approaches and methods of technical condition diagnostic [17, 20-23]. Modern diagnostic systems are high-tech, complex, intelligent systems that can be built in equipment. During operation and maintenance of special military equipment, it is important to control both main and additional parameters. In order to reduce time and increase accuracy of measurements, forecasting of AME (Armament and Military Equipment) state, it is necessary to use intelligent diagnostic systems [10, 24-25]. Non-destructive control methods are the basis of measuring characteristics of small arms, artillery and missile-artillery weapons, wheeled and tracked military equipment, and communication equipment. Non-destructive control methods include

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radiography, ultrasonic defectoscopy, magnetic resonance research methods, and others. Measuring systems that implement the specified measurement methods widely use phaseometry methods [7].

The subject of study in the article is the compensatory method of measuring the phase shift of two harmonic signals, after their two-half-period conversion and summation using as a measure of the phase shift of the reference functions. The aim is to develop a method of implementing a compensatory method for measuring the phase shift of two harmonic signals, which will significantly reduce the component of measurement error due to phase asymmetry of signal transmission channels, by reducing their length, the error component due to instability information signal, as well as to reduce the error component due to the precision measure. Tasks: setting the measuring problem of determining the phase shift of two harmonic signals; analysis of known methods of phase shift measurement and factors that significantly affect the accuracy of measurement, development of a method for implementing the compensation method based on the analysis of the shape of the total signal obtained during the two-half-period transformation; sources of measurement errors for the proposed method. The methods used are methods of conducting a factorial experiment, numerical methods of finding the extremum, methods of probability theory and mathematical statistics, methodology for estimating measurement errors. A method of implementing a compensation method for measuring phase shift using a signal obtained by adding harmonic signals after their two-and-a-half-period conversion is proposed. As a measure of phase shift, it is proposed to use a function synthesized by computational means. The algorithm of realization and the list of measuring and auxiliary procedures for realization of the given method of definition of a phase shift is offered. The sources of measurement error, which are characteristic of the proposed method of measurement, are considered. The use of this method of measurement will reduce the component measurement error due to the phase asymmetry of the signal transmission channels, and reduce the cost of creating a pre-cession measure of phase shift and comparator.

The subject of study in this article is compensatory method of phase shift measurement of two harmonic signals after their bisemiperiodic conversion and summation using as measure of phase shift reference functions. The aim is to develop compensatory method implementation for phase shift measurement of two harmonic signals, which will significantly reduce measurement error component due to signal transmission channels phase asymmetry, by reducing their length, error component due to instability information signal, as well as to reduce error component due to precision measurement. Tasks: setting the measure problem of phase shift determination of two harmonic signals; analysis of phase shift measurement known methods and factors that significantly affect measurement accuracy, development of compensatory method implementation based on total signal shape analysis obtained during bisemiperiodic transformation; measurement errors sources for the proposed method. The used methods are those making factorial experiment, numerical methods of extremum finding, methods of probability theory and mathematical statistics, methodology for estimating measurement errors. Compensatory method implementation for phase shift conversion using signal obtained by adding harmonic signals after their bisemiperiodic transformation has been proposed. It is proposed to use function synthesized by computational means as phase shift measure. Algorithm of realization and the list of measuring and auxiliary procedures for realization of given method of phase shift definition have been offered. Sources of measurement error, which are characteristic of measurement proposed method have been considered. The use of this measurement method will reduce the component measurement error due to signal transmission channels phase asymmetry, and reduce the cost of creating a pre-cession measure of phase shift and comparator.

2. Related work

Nowadays, phase measurement methods are used in such fields as radar and radio navigation, aviation and space engineering, geodesy, mechanical engineering, communication, non-destructive testing [3, 5, 7, 11, 26-29]. Transformation of various physical processes and, accordingly, their values into phase shift of two harmonic signals ensures simplicity of measurement procedure implementation and achievement of fairly high accuracy. Methods of converting physical quantities into phase shift of two harmonic signals have gone beyond traditional application in radio engineering, navigation and communication and are quite often used in experimental physics, radio physics, non-destructive testing, experimental medicine, the latest branches of science and technology during research [9, 13, 15, 18, 30]. Phase measurement methods and information and measurement systems created on its basis made it possible to solve a number of scientific and technical tasks related to precise measurement of distances, time intervals, angles and analysis of signal fields characteristics of different physical nature (electromagnetic, optical, acoustic).

When solving certain practical tasks, there is a need to measure phase shifts in frequency range from infra-low to ultra-high frequencies in the presence of noise and interference in a wide dynamic range of investigated signals amplitudes. For harmonic signals such concepts as phase, initial phase, phase shift and delay time are used in measuring technology. At present, determination of phase shift is of greatest interest for phasometry. Under the phase shift, in accordance with the existing regulatory documents, the modulus of the difference of the initial phases of the frequencies of two harmonic signals of some is accepted.

The most complete classification of methods for measuring phase shifts is given in the work [16].

According to phase shift measurement principle, compensation method and method of converting phase shift into other values such as voltage, time interval, geometric parameters of oscillographic images of investigated signals have been distinguished.

Compensatory measurement method is based on balancing (compensating) phase shift between two harmonic signals, that is, reducing phase shift of signals to zero by adjusting one of the signals or both signals phase using controlled measuring phase shifter (or phase shift measure) [6, 16]. Measurements are carried out at fixed intermediate frequencies, which ensures the correct operation of phase shifter and system for indicating phase fall of signals. This method ensures achievement of high measurement accuracy, close to accuracy of measuring phase shifters.

This method allows to determine phase shift of signals after its previous conversion into another intermediate value, such as voltage, current, displacement of oscilloscope electronic beam, time interval, etc. Main known ways of implementing this method have been considered.

Additive method of processing signal voltages (voltage addition method) [1, 16] is based on vector addition of signals. In the case of adding harmonic signals, such a signal has been obtained whose amplitude value will depend on amplitude values of input signals and phase shift between them. Since value of phase shift is received from results of three harmonic signals amplitudes measurement, this method is sometimes called “three voltmeters method”.

In order to simplify phase shift measuring process by adding voltages, procedure for automatically adjusting level of input signals is carried out [8]. Then value of output signal amplitude will depend exclusively on phase shift value. Multiplicative method of signal processing (voltage multiplication method) [4, 16] is based on the fact that as a result of multiplying two harmonic signals, it is possible to get signal that has constant component in its composition, value of which depends on amplitudes value of output signals and phase shift between them , and harmonic component. Similarly, as for the method of voltage addition, in order to simplify phase shift measuring process, automatic adjustment procedure of input signals level is carried out.

When using oscillographic method, as shown in the work [14, 16], measured phase shift value is determined by nature and shape of oscillograms. Phase shift measurement by the oscillographic method is carried out using linear or sinusoidal sweep.

It is possible to measure phase shift of two harmonic signals using linear sweep using multi-channel oscilloscope. To measure phase when using sinusoidal sweep, one of measured voltages is applied to horizontal deviation channel, and the second signal to vertical deviation channel. Under action of these voltages, it is possible to get interference figure on the screen - ellipse, axes of which are turned by some angle relative to horizontal and vertical axes of screen. By measuring the dimensions of ellipse edges, it is possible to determine phase shift value.

Method of converting signal phase shift into time interval is presented in the work [16]. Phase shift of sinusoidal signals is uniquely determined by signals time delay. By determining time delay of signal between signals characteristic points, for example, between moments of crossing signals of zero level in case that signs of the derived signals coincide. This makes it possible to reduce process of measuring phase shifts to time intervals determination, provided that frequency or period of input signals is known.

Disadvantages of known methods include the following [1, 4, 6, 8, 14, 16]:

- Significant impact on accuracy phase shift measurement of error component, which is caused by phase asymmetry of signal transmission channels;

- Presence of two channels for conducting analog-to-digital conversion of input signals, which leads to need for mutual synchronization of clock generators frequency for each of the channels;
- External and internal noises have a significant impact on the accuracy of the phase shift measurement;
- Non-linear grading characteristics.

Therefore, purpose of the work is to develop compensatory method for measuring the phase shift, which will allow to reduce the measurement error during technical condition diagnostic of modern weapons and military equipment, as well as to reduce the costs of measuring equipment in intelligent diagnostic systems.

3. Methods and materials

Apparatus for conducting factorial experiment is considered like basis for proposed compensatory method implementation of phase shift measurement of two harmonic signals.

Analysis of sources [19] concerning factorial experiment organization has shown that, as a rule, this process has been carried out in the following sequence:

- Determination of quantity value, that can be investigated;
- Justification of functions set that probably describes investigated signal;
- Selection of indicator that characterizes coincidence degree of studied signal and function that describes it;
- Criterion appointment, on the basis of which decision is made that investigated signal is described by specific functional dependence from set of possible ones;
- Choosing from set of functions the one that most fully corresponds to investigated signal using selected indicator based on accepted decisive criterion;
- Decision that studied signal has the same characteristics as the selected functional dependence.

In this article, the factorial experiment is understood as the selection of the ratio that most fully describes the shape of the curves of the total signal obtained as a result of the summation of two harmonic signals after carrying out a two-semi-periodic transformation.

Analysis of well-known methods measurements given in works [1, 4, 6, 8, 14, 16] has shown that this list of operations is close to compensatory method of measurement, so scheme of phase shift measurements using compensatory method, which is presented in Fig. 1, includes the following basic procedures:

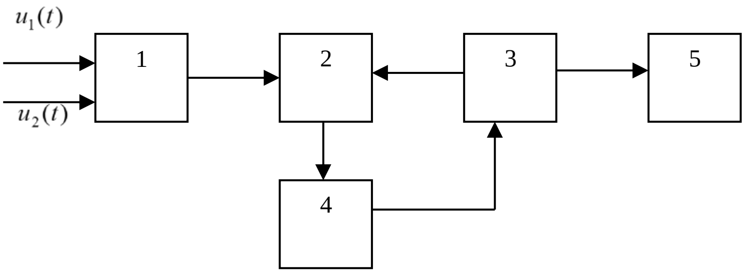

Figure 1: Scheme of compensatory method of phase shift measurement using bisemiperiodic transformation, where:
1 - carrying out bisemiperiodic conversion of input signals and their summation,
2 - calculation of discrepancy degree between measured value of phase shift and reference function,
3 - formation of a large number of phase shift reference functions,
4 - formation of information about coincidence of measured phase shift values and reference function,
5 - presentation of information about phase shift value.

The bisemiperiodic conversion of input signals mean that the input sinusoidal signals are converted into two half-cycles, with their subsequent summation. According to the form of receiving the signal, the secondary phase shift. The operation of converting a sinusoidal signal in two half-cycles can be carried out, for example, using a diode bridge or a diode-resistive converter.

It is needed to consider in more detail's measurement procedure and the list of operations that are performed when measuring harmonic signals phase shift using this method.

4. Experiments, results and discussions

Imagine that there are two harmonic signals $u_1(t)$ i $u_2(t)$, which have phase shift one relative to the other equal to $\Delta\varphi$, which belongs to the interval from 0 to 2π. Based on the fact that phase shift measurement is relative measurement, then changes in signals may be in the following form:

$$u_1(t) = U_{m1}\, cos(2\pi f t), \tag{1}$$

$$u_2(t) = U_{m2}\, cos(2\pi f t + \Delta\varphi), \tag{2}$$

where: U_{m1},U_{m2} is amplitude of signals and $u_1(t)$ and $u_2(t)$ respectively; $f = \frac{1}{T}$ is signal frequency; T is signal tracking period.

Time diagram for signals $u_1(t)$ and $u_2(t)$, which have certain phase shift relative to each other by angle $\Delta\varphi$, is shown in Fig. 2.

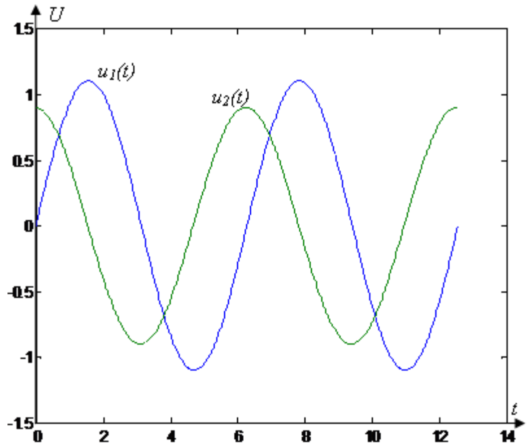

Figure 2: Time diagram for signals $u_1(t)$ and $u_2(t)$

To ensure required accuracy of phase shift measurement, it may be necessary to perform such auxiliary operations as hardware filtering of input signals in order to reduce influence of interference, presence of which is due to the influence of external factors and their amplification to improve the sensitivity of $\Delta\varphi$ value measurement. After performing the above procedures, the signals are sent to the bisemiperiodic converters. It is possible to receive signals at the outputs of converters:

$$u_1^{/}(t) = |u_1(t)| = |U_{m1}\, cos(2\pi f t)|, \tag{3}$$

$$u_2^{/}(t) = |u_2(t)| = |U_{m2}\, cos(2\pi f t + \Delta\varphi)|. \tag{4}$$

Time diagram for these signals is shown in Fig. 3.

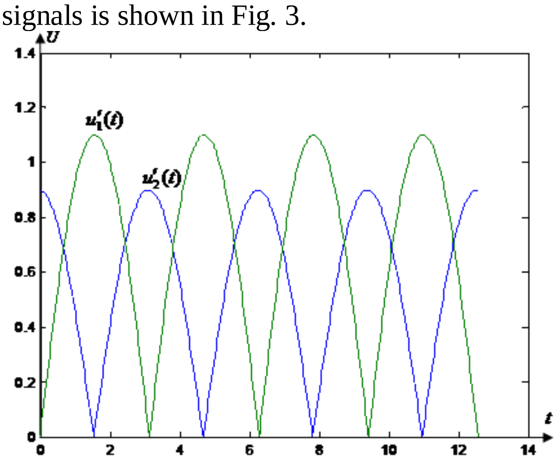

Figure 3: Time diagram for signals $u_1^{'}(t)$ and $u_2^{'}(t)$

Summing up $u_1^{/}(t)$ и $u_2^{/}(t)$, signal $u_{\Sigma}^{'}(t)$ has been obtained, that is described by the following relation [14], time diagram of which is shown in Fig. 4:

$$u_{\Sigma}^{/}(t)=\begin{cases} U_{1\min}+\dfrac{U_{1\min}-U_{2\min}}{t_{1.2}}t+(U_{1\max}'- \\ -\dfrac{U_{1\min}+U_{2\min}}{2})\times \\ \times\sin\left(\left(2f-\dfrac{2\pi f}{\Delta\varphi}\right)t\right)...t_1\le t<t_2 \\ U_{2\min}+\dfrac{U_{2\min}-U_{1\min}}{t_{2.3}}t+ \\ +(U_{2\max}'-\dfrac{U_{2\min}+U_{1\min}}{2})\times \\ \times\sin\left(\left(\dfrac{2\pi f}{\Delta\varphi}\right)t\right).........\ ......t_2\le t<t_1 \end{cases} \tag{5}$$

where: U_{1min} and U_{2min} is local minima of function on the interval from 0 to ${}^{\mathrm{T}}\!/_{2}$; $U_{1max}' = (U_{m1}+U_{m2})\,cos\frac{\Delta\varphi}{2}$, is local maximum on time interval $t_{1.2}=\frac{1}{2f}-\frac{\Delta\varphi}{2\pi f}$; $U_{2max}' = (U_{m1}+U_{m2})\,sin\frac{\Delta\varphi}{2}$, is local maximum on time interval $t_{2.1}=\frac{\Delta\varphi}{2\pi f}$.

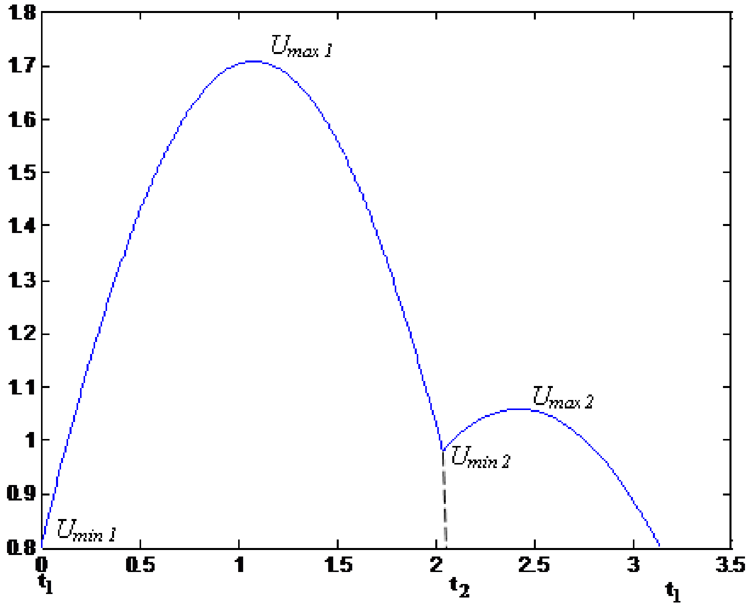

Figure 4: Time diagram for signal $u_{\Sigma}^{'}(t)$

After performing amplitude-time analogue-digital conversion of signal $u_{\Sigma}^{'}(t)$, according to the presented in the work [16], it is possible to obtain the vector:

$$u_{\Sigma\partial}^{'}(t_i) = (U_1, U_2, \ldots U_i \ldots U_n), \tag{6}$$

where: U_i is instantaneous values of signal $u_{\Sigma}^{\prime}(t)$ at the i-th moment of time, obtained as a result of analogue-digital conversion; n is number of counting obtained during analogue-digital conversion.

Selection of counting number is based on the following conditions:

$$n\cdot\Delta t=\frac{T}{2},\ n\ge n_{min},\ \Delta t\ge t_p, \tag{7}$$

where: Δt is discretization period; t_p is time of one cycle of analogue-to-digital converter; n_{min} is the minimum number of sampling points necessary to restore the original signal.

Signal $u'_{\sum\partial} = (U_1, U_2, \dots U_i \dots U_n)$ enters calculator of difference between measured value and reference signal, where values are recorded in memory device.

In order to reduce computational operations and simplify procedure for determining Δφ, it is advisable to switch from time counts to signal phase counts by introducing the assumption that:

- If before starting to determine phase shift Δφ, frequency of signals $u_1(t)$ та $u_2(t)$ is known, then value $\Delta\varphi_D$, which is equivalent to the sampling period, can be determined as following:

$$\Delta\Phi_D = \frac{\Delta t \cdot 2\pi}{T}; \quad (8)$$

- After amplification of signals $u_1(t)$ and $u_2(t)$, $U_{m1}$and U_{m2} have values close to the measurement limit of analogue-digital converter;
- Operation of analogue-digital conversion begins at the time when $u_1(t) = 0$.

Then, as discrete reference function, it is advisable to use:

$$u'_{\sum e}(\Delta\varphi) = (U_{e1}, U_{e2}, \dots U_{ei} \dots U_{en}) == 2U_m(|sin\,\varphi_i| + |sin(\varphi_i + \Delta\varphi)|), \quad (9)$$

value of quantity $U_m$will be chosen, for example, equal to measurement limit of analogue-to-digital converter.

Then, taking into account the above mentioned, formulation of phase shift determination problem of harmonic signals $u_1(t)$ i $u_2(t)$ is formulated as follows: from entire set of reference functions $u'_{\sum e.}(\varphi_i)$, it is needed to choose such j –in function,

$$u'_{\sum e.j}(\varphi_i) = \left(U_{e.j.1}, U_{e.j.2}, \dots U_{e.j.i}, \dots U_{e.j.n}\right) = 2U_m(|sin\,\varphi_i| + \left|sin(\varphi_i + \Delta\varphi_j)\right|), \quad (10)$$

which most fully corresponds to the signal

$$u'_{\sum\partial}(\varphi_i) = (U_1, U_2, \dots U_i \dots U_n). \quad (11)$$

It is known that such an indicator as correlation coefficient is widely used as indicator of the degree of several functions' closeness. The ratio for determining this value in the case of $u'_{\sum D}(\varphi_i)$ and $u'_{\sum e.j}(\varphi_i)$ in accordance with the research [18] will be presented as follows:

$$K_{d.j}\left[u'_{\sum\partial}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_j)\right] = \frac{\sum_{i=1}^{n}(U_{e.j.i} - \bar{U}_{e.j}) \cdot (U_i - \bar{U})}{\sqrt{\sum_{i=1}^{n}(U_{e.j.i} - \bar{U}_{e.j})^2}\sqrt{\sum_{i=1}^{n}(U_i - \bar{U})^2}} \quad (12)$$

where: $\bar{U} = \frac{1}{n}\sum_{i=1}^{n} U_i$, $\bar{U}_{e.j} = \frac{1}{n}\sum_{i=1}^{n} U_{e.j.i}$, is the average arithmetic value for vector of functions $u'_{\sum D}(\varphi_i)$ and $u'_{\sum e.j}(\Delta\varphi_j)$ respectively.

Taking into account the above mentioned, it is needed to formulate the measurement task of Δφ phase shift determination of signals $u_1(t)$ and $u_2(t)$ as follows: from entire set of reference functions of phase shift, it is needed to choose function that will provide maximum value of correlation coefficient between it and the discrete signal $u'_{\sum\partial}(\varphi_i)$,

$$K_{d.j}\left[u'_{\sum\partial}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_j)\right] \rightarrow max. \quad (13)$$

It can be seen from formulation of measurement task that it is issue of finding maximum of correlation coefficient. This class of problems can be solved using analytical or numerical methods. Analysis of well-known software tools [2], which are widely used today, has shown that they use numerical methods for finding extremum. In turn, numerical methods for finding the extremum of function are divided into gradient methods, methods using second derivatives, and direct methods. As a rule, when solving extremum search problems using gradient methods and methods using second derivatives there is faster convergence than when using direct methods. However, application of methods that use derivatives to solve this problem leads to difficulties caused by functional dependence of studied function. Direct methods do not require the condition of regularity and continuity of investigated function and existence of derivative. Analysis of change in correlation coefficient when determining phase shift shows that this function is quasiconvexity. Determination for which the maximum value of correlation coefficient is ensured will be carried out using method of golden section. Choice of this method compared to known methods, such as dochometric, is due to the fact that it requires fewer iterations.

Algorithm for finding the maximum using golden section method looks like this:

Previous stage. Determination of admissible final length of uncertainty l.

Selection of minimum value of this indicator is supposed to be carried out based on requirements for solution error of phase shift measurement problem, taking into account the accuracy characteristics of technical means involved in process of analogue-digital signal conversion and additional operations, rounding errors during calculations. As can be seen from condition of phase shift measurement and list of conversion operations of input harmonic signals $u_1(t)$ and $u_2(t)$, initial uncertainty interval is interval equal to $[0, \pi[$ radian. Length of new uncertainty interval for the first iteration is determined using the ratios given in the work [12]:

$$\Delta_{\lambda 1} = (1-\alpha) \cdot \pi, \tag{14}$$

$$\Delta_{\mu 1} = \alpha \cdot \pi, \tag{15}$$

where α is coefficient that lies in the interval $0 < \alpha < 1$.

It is recommended to carry out calculations: $\alpha = 0{,}618$. This is the recommended value for the maximum search algorithm using the golden section method. This value can be changed depending on the characteristics of analogue-to-digital converters (ADCs) and the software that will be used in the development of specific measuring systems. Calculation of correlation coefficient for $K_{d.j}\left[u'_{\sum D}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_{\lambda 1})\right]$ and $K_{d.j}\left[u'_{\sum \partial}(\varphi_i), u'_{\sum e.j}\left(\Delta\varphi_{\mu 1}\right)\right]$ is made using relations (9) i (12).

It is needed to calculate $K_{d.j}\left[u'_{\sum D}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_{\lambda 1})\right]$, consider that $\kappa = 1$ and move to main stage.

Main stage.

Step 1. If$\Delta_{b.k} - \Delta_{a.k} \leq l$, then stop and accept that value of phase shift is equal to

$$\Delta\varphi = \frac{\Delta\varphi_{b.k} - \Delta\varphi_{a.k}}{2}, \tag{16}$$

where $\Delta\varphi_{a.k}$ -is beginning of uncertainty interval at k iteration; $\Delta\varphi_{b.k}$ is end of uncertainty interval at k iteration.

If

$$K_{d.j}\left[u'_{\sum D}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_{\lambda 1})\right] > K_{d.j}\left[u'_{\sum \partial}(\varphi_i), u'_{\sum e.j}\left(\Delta\varphi_{\mu 1}\right)\right] \tag{17}$$

and shift to step 3, if

$$K_{d.j}\left[u'_{\sum D}(\varphi_i), u'_{\sum e.j}(\Delta\varphi_{\lambda 1})\right] \leq K_{d.j}\left[u'_{\sum \partial}(\varphi_i), u'_{\sum e.j}\left(\Delta\varphi_{\mu 1}\right)\right] \tag{18}$$

and shift to step 2.

Step 2. Define:

$$\Delta\varphi_{a.(k+1)} = \Delta\varphi_{\lambda.k}, \tag{19}$$

$$\Delta\varphi_{b.(k+1)} = \Delta\varphi_{b.k}, \tag{20}$$

$$\Delta\varphi_{\lambda.(k+1)} = \Delta\varphi_{\mu.k}, \quad \Delta\varphi_{\mu(k+1)} = \Delta\iota_{a.k} + \alpha(\Delta\varphi_{b.(k+1)} - \Delta\varphi_{a.(k+1)}). \tag{21}$$

Calculate $K_{d.j}\left[u'_{\sum \partial}(\varphi_i), u'_{\sum e.j}\left(\Delta\varphi_{\mu(k+1)}\right)\right]$ and shift to step 4.

Step 3. Define:

$$\Delta\varphi_{a.(k+1)} = \Delta\varphi_{a.k}, \tag{22}$$

$$\Delta\varphi_{b.(k+1)} = \Delta\varphi_{\mu.k}, \tag{23}$$

$$\Delta\varphi_{\mu.(k+1)} = \Delta\varphi_{\lambda.k}, \Delta\varphi_{\lambda(k+1)} = \Delta\varphi_{a.(k+1)} + (1-\alpha)(\Delta\varphi_{b.(k+1)} - \Delta\varphi_{a.(k+1)}). \tag{24}$$

Calculate $K_{d.j}\left[u'_{\sum \partial}(\varphi_i), u'_{\sum e.j}\left(\Delta\varphi_{\lambda(k+1)}\right)\right]$ and shift to step 4.

Step 4. Replace k with $k+1$ and go to step 1.

Main sources of error in this phase shift measurement method are:

- Error caused by amplitude-time transformation;
- Error due to formation of measurement interval;
- Error due to presence of noise interference, influence of external environment and internal environment of measuring device;
- Error due to non-identity between characteristics of the first and second measuring channels;
- Rounding error when searching for the maximum value of correlation coefficient;
- Error of the reference function formation.

Conducting experimental studies with obtaining numerical values is planned after the completion of work on the synthesis of the methodology for calculating the requirements for the ADC, computing equipment and software. In our opinion, it is possible to obtain sufficiently adequate estimates of compensation of errors, possibly after the completion of work on the synthesis of the methodology for calculating the requirements for ADCs, computing equipment and software.

5. Conclusions

Method of measuring phase difference of two harmonic signals, which can be attributed to compensation method of measurement has been proposed. Distinctive feature of this method is the use as measurement information about value of above-mentioned signal measurement form obtained as a result of addition of harmonic signals curves after carrying out their bisemiperiodic transformation, and as benchmark, with which the measured value is compared, function synthesized using computing tools.

Determination of phase shift coincidence, which is measured and formed by reference function, has been carried out on the basis of criterion of reaching correlation coefficient maximum. To solve this problem, algorithm for finding the extremum of functional dependence of correlation coefficient on a set of reference functions based on the golden section method has been proposed.

Application of specified differences in this method compared to known methods based on analogue-digital amplitude-time conversion makes it possible to:

- Reduce component of measurement error caused by phase asymmetry of signal transmission channels by reducing their length;
- Perform one operation of analogue-to-digital conversion of signal to be analyzed, instead of two, which in turn makes unnecessary synchronization of analogue-to-digital conversion for each signal processing and transmission channel;
- Do not use high-precision phase shift standards;
- Significantly to reduce requirements for accuracy of normalization of input signals amplitudes.

Main sources of error in this method of measuring the phase shift have been determined.

Further work will be devoted to the practical verification of the obtained results using physical model of proposed method of phase shift measurement.

Use of proposed principle of phase shift determination will significantly reduce complexity of measuring systems due to simplification of circuit solutions (the need to use one transmission path and digital signal processing) in comparison with methods and means currently used (digital processing and signal transmission is carried out for each harmonic signal on separate path). And this, in turn, will make it possible to save material resources for control of technical characteristics of AME and its components (about 10%) during tests at stages of development and production of sample without reducing the measurement quality.

In the future, it is advisable to conduct work on formation of analytical ratios that describe relationship between spectral characteristics of signal analysed depending on change in phase shift under the condition of unequal amplitudes of harmonic signals. Which, in turn, will make it possible to develop such measurement methods, use of which reduces requirements for measuring equipment without reducing accuracy of measurements.

Proposed method of measurement and diagnostics can be "built-in" in artificial intelligence system of diagnostics to determine state of AME during its operation and maintenance.

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