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PRINCIPLES OF MEASUREMENT OF PHASE SHIFT OF TWO –HARMONIC SIGNALS USING FULL-WAVE TRANSFORMATION

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The article analyzes the known methods of measuring the phase shift of two harmonic signals identified their shortcomings. Considered a list of measuring and auxiliary operations for ampletudnovremennogo analog-to-digital conversion. Methods measurable-rhenium values of the phase shift on the basis of a full-wave transformation

Ключевые слова: *phase shift, harmonic signal, function maximum, extremum, phasemetry.*

Phase methods of measurement, transformation and transmission of information hold an important place in the theory and practice of measurement.

These methods are widely used in scientific fields such as: radiolocation and radio navigation, aviation and space techniques, geodesy, instrument engineering, communication, non-destructive control systems and the sphere of their use is constantly increasing.

Carrying out the measurement of the phase shift signal is based on model of harmonic signal, that has no change of its parameters on infinite time interval [1]. This model is ideal, in practice the model with finite time window is used, what means that measurement is carrying out on finite time interval.

For harmonic signals in measuring techniques such concepts are use: phase, initial phase, phase shift and time delay.

At the moment the measuring of phase shift has the greatest interest in phasemetry. The phase shift [2] is module of difference between the initial phases of two harmonic signals of one frequency.

The most complete classification of methods for measuring the phase shift of harmonic signals is given in works[1,3,4].

In different technical systems the methods for measurement based on transformation of phase shift in another values are widely used. These intermediate values are voltage, current, correlation function, the time interval. As a rule, the determination of these values is carried out using digital measurement methods.

The disadvantages of well-known methods are [1]:

- the necessity of mutual synchronization of clock oscillator frequency in the analog-to-digital conversion of the input signals;
- the necessity of the operation of analog-to-digital conversion of the two input signals;
- the use of phase difference calibrators
- cosinusoidal character of the scale.

The purpose and problem formulation

To determine list of measuring operations required for measuring the phase shift of two harmonic signals, using their full-wave transformation. To consider the possible ways of determining the value of the measured physical parameter.

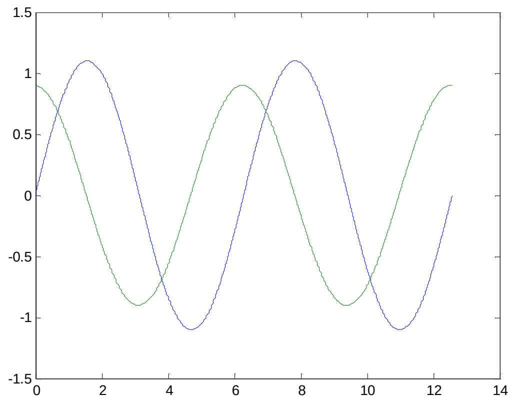
The statement of the main research material

Suppose there are two harmonic signals $u_1(t)$ and $u_2(t)$, that have phase shift relative to one another equals $\Delta\varphi$, belonging to the interval from 0 to 2π. Based on the fact that the measurements of phase shift are relative measurements, then write the change of signals $u_1(t)$ and $u_2(t)$, in the form

$$u_1(t) = U_{m1}\cos(2\pi ft) \quad (1)$$
$$u_2(t) = U_{m2}\cos(2\pi ft + \Delta\varphi)$$

where: U_{m1}, U_{m2} - amplitude of signals $u_1(t)$ and $u_2(t)$ accordingly; $f = \frac{1}{T}$ - signal frequence; T - period of the signal sequence.

Time diagram for these signals, that have some phase shift relative to one another on angle $\Delta\varphi$, is shown in picture 1.



Picture 1 – Time diagram of signals $u_1(t)$ and $u_2(t)$

Consider the list of measuring and additional operations, which are held in the process of the input signal transformation.

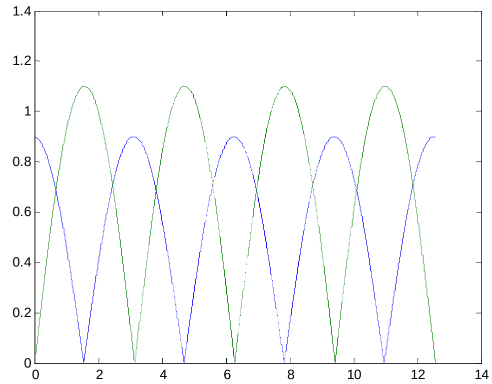
To maximize the sensitivity level the normalization of the input signals according to the the level is carried out. In this case, assume that the amplitude values of the signals $u_1(t)$ and $u_2(t)$ differ from one another by the value not exceeding 10%.

To reduce the influence of noise, the existence of which is due to external factors, hardware filtering for each of the input signals is carrying out.

After this operations signals $u_1(t)$ and $u_2(t)$ come on full-wave rectifier, whereby we obtain:

$$u_1^{/}(t) = |u_1(t)| = |U_{m1}\cos(2\pi f t)|$$
$$u_2^{/}(t) = |u_2(t)| = |U_{m2}\cos(2\pi f t + \Delta\varphi)|\,.$$

Time diagrams for these signals are shown in picture 2.



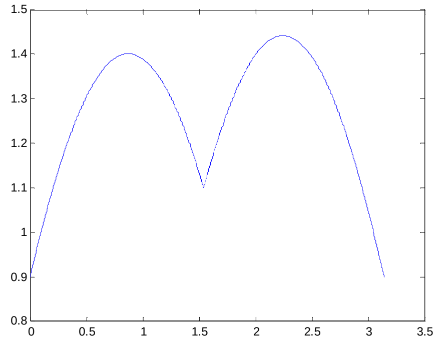
Picture 2 – Time diagram of signals $u_1'(t)$ and $u_2'(t)$

After completing the summation of signals $u_1^{/}(t)$ and $u_2^{/}(t)$, the signal $u_{\sum}'(t)$ is obtained, that can be described by the following ratio:

$$u_{\sum}^{/}(t) = \begin{cases} U_{1\min} + \dfrac{U_{1\min} - U_{2\min}}{t_{1.2}} t + \\ + (U'_{1\max} - \dfrac{U_{1\min} + U_{2\min}}{2}) \times \\ \times \sin\left(\left(2f - \dfrac{2\pi f}{\Delta\varphi}\right) t\right) ....для\, 0 \le t < t_2 \\ \\ U_{2\min} + \dfrac{U_{2\min} - U_{1\min}}{t_{2.3}} t + \\ + (U'_{2\max} - \dfrac{U_{2\min} + U_{1\min}}{2}) \times \\ \times \sin\left(\left(\dfrac{2\pi f}{\Delta\varphi}\right) t\right) ....для\, t_2 \le t < t_3 \end{cases}$$

where: $U_{1\min}$ and $U_{2\min}$ - local minimm of function on the interval from 0 to $T/2$; $U'_{1\max} = (U_{m1} + U_{m2})\cos\dfrac{\Delta\varphi}{2}$ - local maximum on the time interval $t_{1.2} = \dfrac{1}{2f} - \dfrac{\Delta\varphi}{2\pi f}$; $U'_{2\max} = (U_{m1} + U_{m2})\sin\dfrac{\Delta\varphi}{2}$ - local maximum on the time interva $t_{2.3} = \dfrac{\Delta\varphi}{2\pi f}$.

Time diagram for this signal for some value of phase shift $\Delta\varphi$ is shown in picture 3.



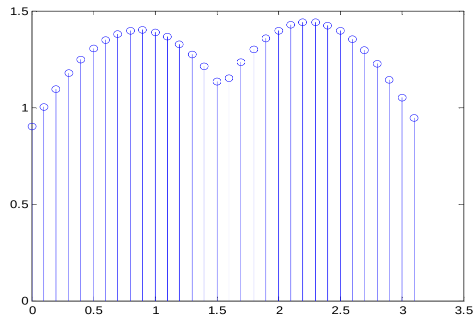
Picture 3 – Time diagram of signal $u_{\sum}'(t)$

After the amplitude-time analog-to-digital conversion of the signal $u_{\sum}'(t)$ according to [1], the vector is obtained:

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

where U_i - the instantaneous values of the signal $u_{\sum}'(t)$, obtained on result of analog-to-digital conversion; n - the number of sampling points of the signal $u_{\sum}'(t)$.

Time diagram for this signal is shown in picture 4.



Picture 4 – Time diagram of signal $u'_{\sum\partial}$

The number of sampling points is choosing from the following requirements:

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

where Δt - sampling interval; t_p - time of one measure analog to digital converter; $n_{\min}$ - minimum number of sampling points required to restore the original signal.

As known, the value $n_{\min}$ is determined using Kotel'nikov and Nyquist theorem.

Then, based on the above material, the following scheme of the measured signal conversion procedure is proposed, shown in picture 5, that includes the following main measurement and auxiliary operations:

1 – carrying out normalization of the input signals $u_1(t)$ and $u_2(t)$ according to the level;

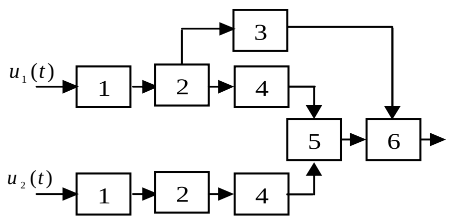
2 – hardware removal of noise caused by the influence of external and internal environment of the signals $u_1(t)$ and $u_2(t)$;

3 – forming signal of starting analog-to-digital conversion operation ;

4 – carrying out full-wave transformation of input signals $u_1(t)$ and $u_2(t)$,

5 –summation of signals $u_1^{/}(t)$ and $u_2^{/}(t)$;

6 – carrying out analog-digital conversion of the signal $u'_{\sum}(t)$.



Picture 5 – Scheme of carrying out the procedure of the measured signal conversion

This list of measuring operations can be implemented using technical devices.

Suggest that before the measurement of the phase shift we know the frequency of signals $u_1(t)$ and $u_2(t)$, and a during the execution of analog-to-digital conversion in one period of repetition of the signal $u'_{\sum}(t)$ we have enough of the number of sampling points. Then, for reducing the volume of computer data it is advisable to go from the signal change function according to time, to changing function according to the phase value $\Delta\varphi_{\partial}$ using the ratio:

$$\Delta\varphi_{\partial} = \frac{\Delta t \cdot 4\pi}{T}$$

In [2] shown, that according to changing the value of phase shift $\Delta\varphi$ of signals $u_1(t)$ and $u_2(t)$, signal $u^{/}_{\sum}(t)$ has values such as $U_{1\max}$, $U_{2\max}$, $U_{1\min}$, $U_{2\min}$, $\Delta t_{2.1}$ and $\Delta t_{3.2}$ changed, as well as actually waveform of $u^{/}_{\sum}(t)$.

Then, based on the foregoing, it is necessary to measure the values $U_{1\max}$, $U_{2\max}$, $U_{1\min}$, $U_{2\min}$, $\Delta t_{2.1}$ and $\Delta t_{3.2}$, or waveform of signal $u^{/}_{\sum}(t)$, and from the known values actually to measure value $\Delta\varphi$.

The solution of this measuring task is proposed to solve using one of the methods:

- oscillographic.

The essence of this method consists of the fact that the digital oscilloscope displays signal $u'_{\sum\partial}$ on screen. Using the channel of horizontal deviation, the values $\Delta t_{2.1}$, $\Delta t_{3.2}$ and $f = \frac{1}{T}$ are being determined.

Then the value $\Delta\varphi_1$ using foregoing parameters $\Delta t_{2.1}$ and $f = \frac{1}{T}$ can be determined based on ratio:

$$\Delta\varphi_1 = 2\pi f \cdot \left(\frac{1}{2f} - \Delta t_{2.1}\right).$$

And from the known values $\Delta t_{3.2}$ and $f = \frac{1}{T}$ the value $\Delta\varphi_2$ can be calculated as:

$$\Delta\varphi_2 = 2\pi f\ \Delta t_{3.2}.$$

The phase shift $\Delta\varphi$ is defined as the average of values $\Delta\varphi_1$ and $\Delta\varphi_2$.

The advantage of this method of measurement relative to well-known oscillographic methods of phase shift measurement of full-wave signal is the opportunity to carry out measurement using one channel of vertical deviation. This advantage allows to increase the accuracy of measurements with a digital oscilloscope.

- combined method.

The essence of this method of phase shift measurement value $\Delta\varphi$ consists of determining values $U_{1\max}$, $U_{2\max}$, $U_{1\min}$ and $U_{2\min}$ using obtained vector $u'_{\sum\partial} = (U_1, U_2, ...U_i ...U_n)$.

Determining values $U_{1\max}$, $U_{2\max}$, $U_{1\min}$ and $U_{2\min}$ is carrying out by one of the proposed methods in [5], it is assumed that the vector $u'_{\sum\partial} = (U_1, U_2, ...U_i ...U_n)$ was digital filtered, whereby excluded random error component with the required level of accuracy. According to [2] the values of parameters $U_{1\max}$, $U_{2\max}$, $U_{1\min}$ and $U_{2\min}$ and phase shift $\Delta\varphi$ are related by the following relations:

$$U^2_{1\max} = U^2_{m1} + U^2_{m2} + 2U_{m1}U_{m2}\cos\Delta\varphi,$$
$$U^2_{1\max} = U^2_{m1} + U^2_{m2} - 2U_{m1}U_{m2}\cos\Delta\varphi,$$
$$U_{1\min} = U_{m1}\sin\Delta\varphi\ ,$$
$$U_{2\min} = U_{m2}\sin\Delta\varphi\ .$$

Having written the system of any of the above three equations and solved it, the value of phase shift $\Delta\varphi$ can be determined

- using the apparatus of the factorial experiment.

The analysis of source [6] for organizing and conducting factorial experiment shows that as a rule this process is being carried out in following way:

- determination of the values which undergoes research;
- justification of a set of functions that are expected to describe the analyzed signal;
- selection parameter, which characterizes the degree of coincidence of researched signal and functions describing it;
- assignment criteria based on which making decision that the analyzed signal is described by a particular functional dependence of possible sets;
- selection of sets of functions, one of the functions that best matches of the signals using the selected parameter based on the received decisive criteria;
- making decision that researched signal has the same characteristics as chosen functional dependence.

Then, for obtained vector $u'_{\sum\partial} = (U_1, U_2, ...U_i...U_n)$ reference functions $U_{э.j}$ is being determined

$$U_{э.j} = \begin{cases} U_{\min} + (U_{1\max} - U_{\min}) \sin\left(\left(\pi - \frac{\pi}{\Delta\varphi_j}\right)\varphi_i\right) \\ U_{\min} + (U_{2\max} - U_{\min}) \sin\left(\left(\frac{2\pi}{\Delta\varphi_j}\right)\varphi_i\right) \end{cases}$$

that most closely corresponds to the measured value of the phase shift $\Delta\varphi_j$ according to chosen criteria.

Conclusions.

In this article the list of measuring and auxiliary operations for carrying out analog-to-digital conversion, required for measuring the phase shift of the two harmonic signals using a full-wave transformation, has been compiled. The methods of measuring value of phase shift have been determined. As methods of measuring value of phase shift of the two harmonic signals using a full-wave transformation it's proposed to use: oscillographic, combined and using the apparatus of the factorial experiment method. The main principles of implementing each of the above methods have been considered.

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