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PHASE SHIFT METER OF ELECTRICAL SIGNALS

This paper examines theoretical foundations, measurement methodologies, and the practical realization of a phase shift meter designed to measure phase differences between signals of identical frequency but varying amplitudes. The measurement of phase difference between electrical signals is a fundamental task in electrical engineering, electronics, and information and communication technologies. Accurate determination of phase relationships is essential for synchronization in power systems, analysis of communication channels, and training of specialists.

The paper reviews existing approaches to phase shift measurement. Analog methods include phase detectors, balanced mixers, compensation techniques, and direct conversion schemes. Digital methods, implemented mainly on programmable logic devices, comprise correlation analysis, Hilbert transform, and quadrature techniques, offering flexibility and precision. Time-domain methods determine phase difference by measuring delays between zero crossings or characteristic points. Each approach has advantages and limitations, but together they form the basis for modern instrumentation.

The developed device operates in the frequency range of 30 Hz to 20 kHz, with a measurement span from 0° to 360°. Its conversion slope equals 8 mV per degree of phase difference. The lower input voltage limit is 0.3 V, while the upper boundary is defined by protective circuitry. The study showed that when analyzing the dependence of the phase meter's output signal on the phase difference around 170°, the polarity reversal from positive to negative and vice versa occurred at the same phase values (170°–172°), defining a transition region of the signals that takes place without hysteresis. It was found that to ensure stable operation, interference and noise must be eliminated by employing a metallic enclosure.

Experimental results confirm the linearity and reproducibility of the results, demonstrating the suitability of the phase difference measurement device for both scientific laboratories and educational environments.

Keywords: oscillation phase, phase shift measurement, frequency, voltage, amplitude characteristic, frequency response, conversion factor.

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ВИМІРЮВАЧ РІЗНИЦІ ФАЗ ЕЛЕКТРИЧНИХ СИГНАЛІВ

В роботі розглянуто питання практичної реалізації пристрою вимірювання різниці фаз електричних сигналів, що мають однакову частоту та різні величини напруг. Пристрій забезпечує можливість вимірювання різниці фаз електричних сигналів від 0° до 360° в діапазоні частот від 30 Гц до 20 кГц. Коефіцієнт перетворення різниці фаз сигналів становить 8 мВольт на градус різниці фаз. Діапазон напруг вимірюваних сигналів обмежений знизу на рівні 0.3 В; зверху він визначається допустимою робочою напругою елементів захисту вимірювача різниці фаз. Експериментальні дані підтверджують лінійність та відтворюваність результатів, що демонструє придатність пристрою вимірювання різниці фаз як для наукових лабораторій, так і для освітніх середовищ.

Ключові слова: фаза коливаль, вимірювання різниці фаз, частота, напруга, амплітудна характеристика, частотна характеристика, коефіцієнт перетворення.

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PROBLEM STATEMENT

The measurement of phase characteristics of complex electrical signals is important for various fields of energy engineering and electronics. Equally important is the issue of measuring not only the phase magnitude of electrical signal oscillations, but also the phase difference $\Delta\varphi$ between two harmonic signals. Such measurements are used in the analysis and evaluation of the quality and efficiency of electronic systems [1–3].

For example, when determining the magnitude of phase–frequency distortions in electronic amplifiers, it is necessary to obtain the frequency dependence of the phase difference between the input and output harmonic signals [4]. The measurement of voltage phase difference is also a key element in the development of power systems [5]. In this context, synchronization – and thus coordination – of two sources of industrial-frequency alternating voltage (for example, power-generating facilities) requires satisfying the conditions of equal voltage magnitudes and the absence of phase difference between the interconnected lines of the power network being formed.

In modern information and telecommunication systems (ITS), phase-modulated signals are widely used. Determining the efficiency, reliability, and even the level of security of such systems requires knowledge of the actual variations in the phase of information signals.

The control and acquisition of a specific phase difference between signals is a key issue in synchronous signal processing devices, for example, in synchronous detection [6, 7]. In synchronous detection, the phase of the reference signal must exactly match (or be opposite to) the phase of the detected signal. It is under this condition that the advantages of synchronous detection over simple detection are realized.

It is quite logical that measuring the phase difference between two harmonic signals is possible provided that their frequencies are equal. The issue of their amplitudes is also important. The simplest case occurs when both signals have equal amplitude levels; however, in many practical situations this condition is not satisfied. With significant differences in signal voltage magnitudes, it becomes difficult to accurately determine the moments when the signal voltage crosses zero or other characteristic points.

ANALYSIS OF RESEARCH AND PUBLICATIONS

Among the methods for measuring the phase difference of electrical signals, the following categories can be distinguished:

- 1) analog methods (phase detectors, balanced mixers, compensation methods, direct conversion);
- 2) digital methods (correlation method, Hilbert transform method, quadrature methods);
- 3) digital methods are mainly implemented using programmable logic devices;
- 4) time-based methods.

The well-known compensation method for measuring phase shift [8] involves the use of a reference phase-shifting device. A phase detector is used to convert the phase difference between the investigated signal and the signal from the reference phase shifter. By varying the phase of the latter, a zero level at the output of the phase detector is achieved. Under this condition, the phases of the investigated signal and the reference phase-shifted signal become equal. Therefore, the phase of the signal generated by the reference device corresponds to the phase of the investigated signal.

The use of a dual-channel direct digital synthesis signal generator ALT-G20 (an analogue of JDS6600 [9]) makes it possible to implement the compensation method for measuring phase shift. The generator provides high accuracy of synthesized frequency parameters up to 20 MHz with a sampling rate of up to 250 MSa/s. It has two independent outputs. When signals of the same frequency are generated at both outputs, it becomes possible to vary the phase of one channel with a resolution of one degree in the range from 0° to 359°. Thus, this output can produce a signal corresponding to that of a reference phase-shifting device. It can be expected that with such parameters of the phase shifter, the measurement error of the investigated signal phase will be determined by the sensitivity of the phase detector and will not exceed a few degrees. In many practical cases, such an error is acceptable.

Direct conversion methods used for measuring phase shifts are traditionally divided into four groups [8]:

- 1) measurement of phase difference by summing the compared signals;
- 2) measurement of phase difference by multiplying the compared signals;
- 3) measurement of phase difference based on the time delay between the compared signals [10];
- 4) oscilloscope-based methods [11].

The direct conversion method involves transforming the phase difference into another physical quantity, whose parameter carries information about the magnitude of the phase difference.

The direct conversion method involves transforming the phase difference $\Delta\varphi$ into another physical quantity, one of whose parameters contains information about the value of the phase difference $\Delta\varphi$.

FORMULATION OF THE GOALS OF THE ARTICLE

The purpose of this work is to develop a device capable of measuring the phase difference of harmonic signals with different amplitudes in the audio frequency range.

PRESENTING THE MAIN MATERIAL

The proposed phase meter provides the capability to measure the phase difference between oscillations of periodic signals having the same frequency and different amplitudes. The structural diagram of the phase difference meter is shown in Fig. 1.

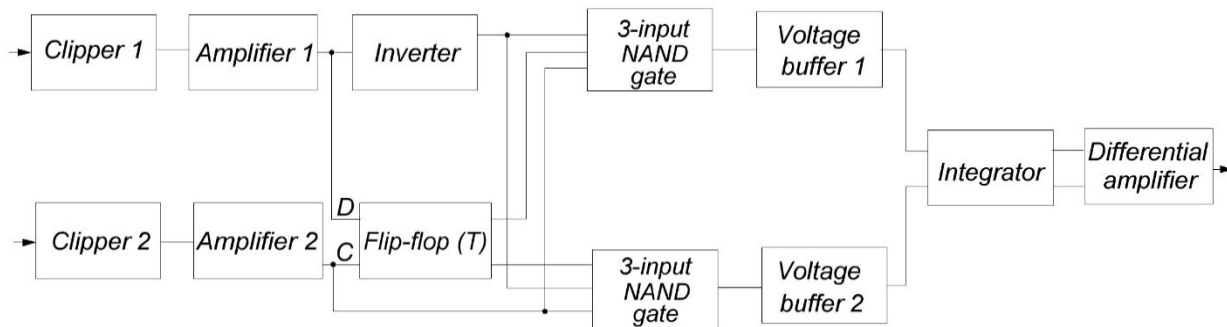


Fig. 1. Block diagram of a phase-shift meter

The measuring device has two inputs with identical parameters. One of the inputs is used for supplying the reference signal, while the other is intended for the signal under investigation. In each channel, the input signal waveform is converted into a rectangular shape using cascade-connected amplitude clippers (Clipper 1, 2) and amplifiers (Amplifier 1, 2). The amplitude clippers are implemented using high-frequency diodes, while the amplifiers are based on KR140UD708 operational amplifiers. In the first channel, the signal is inverted into an antiphase signal (Inverter). By using an SN7474N flip-flop and 3-input NAND logic gates, rectangular signals shifted relative to each other by a time interval proportional to the phase difference of the input signal oscillations are obtained. An integrator is connected between the outputs of the voltage buffers (Voltage Buffer 1 and 2), and its output signal is amplified by a differential amplifier (Differential Amplifier). The phase shift meter is powered from the electrical mains. The output signal of the measuring device is supplied to an analog measuring instrument.

Using the dual-channel direct digital synthesis signal generator ALT-G20 [9], the dependence of the output voltage of the phase meter on the phase difference of the input signal oscillations was investigated. Fig. 2 shows the experimental dependence of the output signal voltage on the phase difference of the input signals at a signal amplitude of 5 V and a frequency of 3 kHz.

Analyzing the obtained dependence, it can be concluded that the circuit provides high linearity of converting the phase difference of the signals into voltage. However, it should be noted that at a phase difference of 170° – 172° , an abrupt change in the polarity of the output signal from a positive to a negative value is observed.

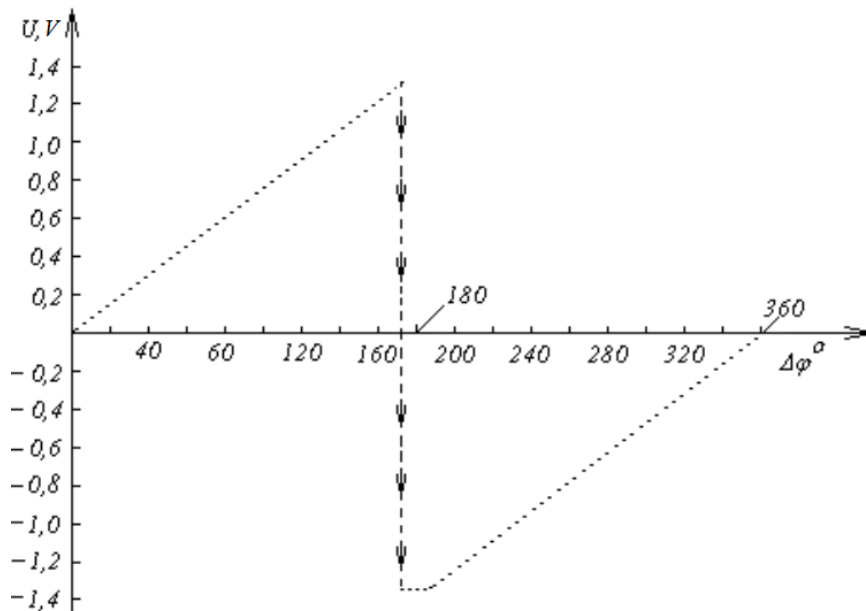


Fig. 2. Dependence of the phase meter output signal voltage on the phase shift of the input signal oscillations

In order to determine the nature of the dependence of the phase meter output signal on the phase difference between signals in the vicinity of 170° , studies of the variation of the output signal were conducted U_{out} during increase and decrease $\Delta\varphi$ of the oscillations of the investigated signals. Fig. 3 shows the obtained experimental dependence

U_{out} on $\Delta\varphi$ in the vicinity of 170° . The polarity change of the phase meter output signal from positive to negative and vice versa occurred at the same phase shift values. The phase difference range of 170° – 172° is a transient process region in which the processes occur without hysteresis. The study of the dependence shown in Fig. 3 was carried out at a signal amplitude of 5 V and a frequency of 3 kHz.

For signal phase shifts exceeding 172° , the output signal of the phase meter remains practically unchanged. The conversion factor of the signal phase difference into the output voltage returns to 8 mV per degree for phase shifts above 190° . Therefore, within the phase difference range of 170° – 190° , the phase meter is incapable of providing reliable phase difference measurements.

The study of the frequency dependence of the phase meter output signal was carried out at equal values of the input voltages $U_{\text{ex1}} = U_{\text{ex2}} = 5V$ and at three values of phase difference. The experimental results are presented in Fig. 4.

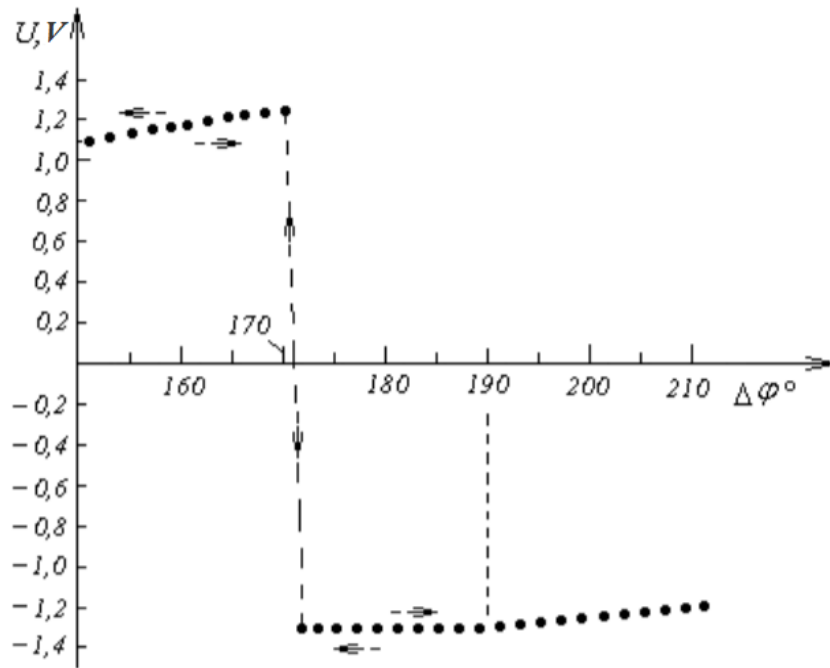


Fig. 3. Dependence of the phase meter output signal magnitude on the phase difference of the input signal oscillations

Within the frequency range from 30 Hz to 20 kHz, the output signal of the phase meter is practically independent of the frequency of the investigated signals. The studies were carried out at $\Delta\varphi = 140^\circ$, $\Delta\varphi = 260^\circ$ and $\Delta\varphi = 300^\circ$, i.e., phase shift regions below and above the 170° – 190° phase anomaly were selected. Therefore, it may be assumed that the obtained frequency dependence is also valid for other phase difference values.

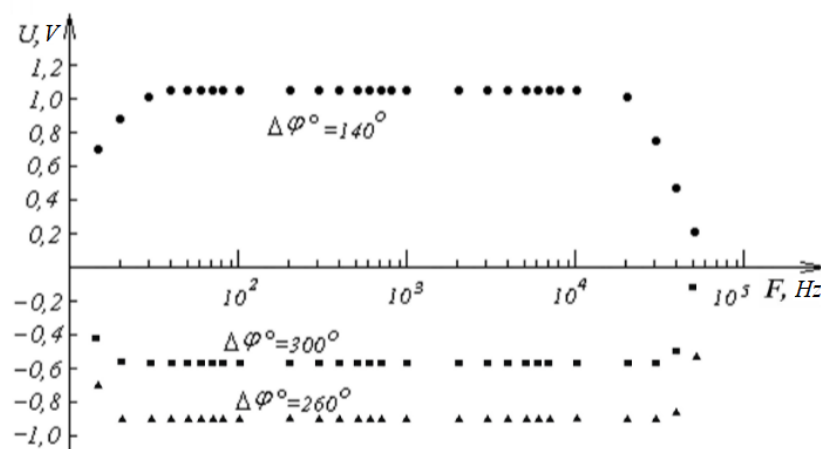


Fig. 4. Dependence of the phase meter output signal magnitude on the frequency of the input signals

The study of the amplitude characteristic of the phase meter, i.e., the dependence of the phase meter output signal on the input voltage, was carried out at a constant voltage value applied to the second input $U_{\text{in2}} = 5V$ and a

variable voltage applied to the first input (U_{in1} – variable). The maximum value and variation range of the voltage applied to the first input were determined by the range of output voltages of the ALT-G20 generator. The measurements were carried out for two values of the signal phase difference, namely at $\Delta\varphi = 120^\circ$ та $\Delta\varphi = 240^\circ$.

Fig. 5 shows the amplitude characteristic of the phase meter obtained as a result of the experimental studies. Starting practically from $U_{in1} = 0.3 B$, the output signal of the phase meter does not depend on the magnitude of the input signal voltage. At present, there is no explanation for the increase in the output signal voltage of the phase meter at $< 0.3 V$.

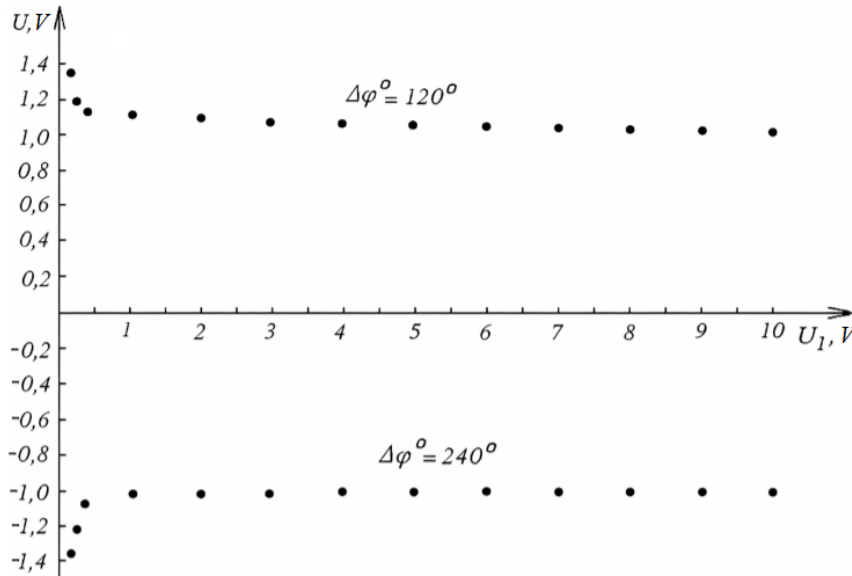


Fig. 5. Dependence of the phase meter output signal magnitude on the voltage at the first input at a constant voltage at the second input $U_2 = 5V$

The experimental results presented above were obtained using the developed phase meter, the external appearance of which is shown in Fig. 6. The device was used to investigate the features of measuring the phase difference of electrical signals under different operating modes. At the initial stages of the experiments, when the phase meter circuit had no protection against external influences, a significant spread of output signal values was observed, which complicated the interpretation of the results and reduced measurement accuracy. This phenomenon was associated with the influence of electromagnetic interference and noise penetrating the device circuitry and affecting the signal conversion process.



Fig. 6. External view of the phase difference meter for electrical signals

In order to eliminate these undesirable factors, it was decided to apply electromagnetic shielding. For this purpose, the device was mounted in a specially manufactured metal enclosure that serves as a protective shield. The

use of such a design solution made it possible to significantly reduce the influence of external interference on the measurement process, stabilize the operation of the phase meter, and ensure the reproducibility of the results.

On the front panel of the device, two equivalent inputs, a power switch, and a power indicator are located, as well as an analog phase difference indicator with a center-zero scale. The use of such an indicator makes it possible to measure not only the magnitude of the phase difference but also its sign. The rear panel of the device contains a socket for connecting the mains voltage, a fuse, and a grounding terminal.

The output signal of the phase meter can also be measured using a digital instrument calibrated in degrees. For this purpose, a socket is provided on the rear side of the device, through which the output voltage of the phase meter is supplied.

CONCLUSIONS FROM THIS STUDY AND PROSPECTS FOR FURTHER RESEARCH IN THIS DIRECTION

The proposed phase shift meter can be used in practical applications where monitoring and analysis of electrical signal interactions are required. In particular, it is suitable for educational laboratory work in electrical engineering and radio electronics to demonstrate the phenomenon of phase shift in electrical circuits with reactive elements, in power supply systems for evaluating the power factor, and in basic automation and control systems where it is important to monitor the synchronism of individual units or devices. Thus, this meter can serve as an accessible and illustrative tool for practical training and applied tasks in technical systems.

The device enables measurement of the phase difference of electrical signals from 0° to 360° within a frequency range from 30 Hz to 20 kHz. The conversion factor of the signal phase difference is 8 millivolts per degree of phase difference. The input signal voltage range is limited at the lower end to 0.3 V; the upper limit is determined by the permissible operating voltage of the phase meter protection components. The power consumption does not exceed 50 W. The obtained experimental results demonstrate the possibility of using the proposed phase shift meter for scientific and educational purposes.

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