Errors in the Hardware of the Device Used to Measure the Average Voltage of Infrared Frequencies

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Abstract

Electronic A method for accurately measuring the average value of an alternating voltage in the infrared frequency range, based on the use of a high-speed electronic digital DC voltmeter and a controlled rectifier-type converter with an averaging link.

Keywords

quasi-stationary mode, hardware errors, silicon diode, linear differential equation.

1. Introduction

The methodological errors of the device were analyzed (Fig.1). To determine the errors of measuring instruments, it is necessary to conduct special studies. In this case, the following assumptions were made: -the averaging element I is an ideal RC circuit without parasitic capacitances and leaks; -the electronic digital DC voltmeter has an infinitely large input resistance, zero errors and instantaneous speed; -the control unit for the key and electronic digital voltmeter generates an ideal square-wave key control signal and a start pulse for the voltmeter at the moments of transition of the instantaneous value of the measured sinusoidal signal through the zero level; -the key K has an infinitely large resistance in the open state, infinitely small resistance in the conducting state, and the construction of sources of emf. and there is no current in the key.

Let us consider the hardware errors of the device caused by the violation of these conditions. The main relationship that determines the error of the device is found when considering the process of changing the voltage across the capacitor of the equivalent circuit in Fig. 3, given in [1]

$$\delta = \frac{U_{vv} - U_{average}}{U_{averagt}} = \frac{an^{|}}{2(a^{|}+n^{|})} clt\frac{a}{2} - 1, \quad (1)$$

where

$$U_{VV} = kclt\frac{a}{2}$$

steady-state voltage value at the output capacitor at the moment of measurement;

$$U_{average} = \frac{2U_m}{n}$$

-average value of measured voltage:

$$k = \frac{anU_m}{a^{|} + n^{|}};$$

$$a = \frac{T}{2RC} - \frac{n}{\omega\tau};$$

$$T = -\frac{2n}{\omega}$$

- period of the measured voltage;

$RC = \tau$-is the time constant of the averaging element. The given errors are used to characterize the accuracy properties of measuring instruments only (such a concept as the reduced error of the measurement result is not used). The systematic and random components of the error of measuring instruments can be considered. These errors are usually expressed as a percentage, but they can also be expressed in relative values.

2. Basic information

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The permissible basic and additional errors are given in the technical descriptions and forms of measuring instruments.

Changes in the resistance R and capacitance C of the capacitor of the averaging element AND affect the measurement result, since this changes the parameter α, on which the error depends1) If the values of R and C are chosen in such a way that a small value of the error is always ensured δ,then even relatively large (2-3%) changes in R and C, which can actually arise as a result of aging or changes in the temperature of these elements, practically do not affect the measurement result.

In general, the partial relative error δ,due to a change in the value α, (due to the change in R and C), can be found from the expression

$$\delta_\alpha = \frac{1}{U_{voltage\,value}} \cdot \frac{\partial U_{vv}}{\partial \alpha} \cdot \Delta\alpha. \qquad (2)$$

Taking into account that

$$U_{vv} = kclh\frac{\alpha}{2} - \frac{\alpha n U_m}{\alpha^{|} + n^{|}} clh\frac{\alpha}{2}, \qquad (3)$$

the partial derivative is

$$\frac{\partial U_{VV}}{\partial \alpha} = k\left[clh\frac{\alpha}{2}\left(\frac{1}{\alpha} - \frac{clh\frac{\alpha}{2}}{2}\right) + \frac{1}{2}\right]. \qquad (4)$$

The relative error after transformations has the form

$$\delta_\alpha = \left(1 - \frac{\alpha}{sh\alpha}\right)\frac{\Delta\alpha}{\alpha}. \qquad (5)$$

With real values $\alpha = (0{,}05 - 0{,}3)$ and $\frac{\Delta\alpha}{\alpha}$ (0,02-0,03) this error does not exceed 0.075%.

2. The final value of the input resistance of the digital voltmeter and the leakage resistance of the averaging element capacitor can also be sources of error. It is advisable to take into account the influence of these resistances according to the scheme in Fig. 1, where they are combined into one equivalent resistance Re, connected in parallel with the capacitor C.

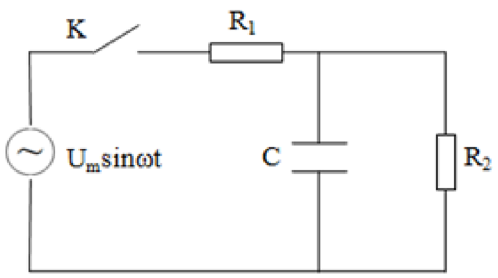

Figure 1: Methodical errors of the device

To increase the reliability of the measurement result, two ways can be used: increasing the measurement accuracy by improving the measuring instruments and measurement methods and increasing the number of measurements.

The output signal - the voltage across the capacitor C - is determined from the difference equation compiled from the differential equations of the circuit in Fig. 1 for cases when the key K is closed and open.

It is convenient to solve this problem by the method of discrete Laplace transform [1].

In quasi-steady-state mode, the voltage across the capacitor U_{vvR} at the moment of opening the key is determined by the expression

$$U_{vvR} = \frac{k_R\left[1 + e^{-\alpha_1(1+R_1/R_2}\right]}{1 - e^{-\alpha_1(1+2R_1/R_2}}, \qquad (6)$$

where

$$k_R = \frac{U_m \pi \alpha_1}{\pi^2 + \alpha_1^2(1 + R_1/R_2)^2};$$

$$\alpha_1 = \frac{T}{2R_1C}. \qquad (7)$$

Partial relative error $\delta_н$, due to the presence of R2, is expressed as

$$\delta_R = \frac{U_{vvR} - U_{vv}}{U_{уст}} \approx \frac{U_{vvR} - U_{average}}{U_{average}}. \qquad (8)$$

Taking into account (6) and the value

$$U_{average} = \frac{2U_m}{\pi}$$

the expression for the relative error $\delta_н$ will take the form

$$\delta_R = \\ = -1 + \frac{\pi^2}{2}\frac{1 + e^{-\alpha_1(1+R_1/R_2}}{1 - e^{-\alpha_1(1+2R_1/R_2}}\frac{\alpha_1}{\pi^2 + \alpha_1^2(1 + R_1/R_2)^2}. \qquad (9)$$

If we expand the exponential functions of the numerator and denominator in a series, perform the appropriate algebraic transformations and discard the higher-order terms, starting from the third (since they are small compared to the terms of the first two orders), then (9) is transformed to the form

$$\delta_R \approx -1 + \frac{1}{1 + 2\frac{R_1}{R_2}} \cdot$$

$$\cdot\left\{1 + \frac{R_1}{2R_2}\alpha_1 + \alpha_1^2\left[\left(1 + \frac{R_1}{R_2}\right)^2 \cdot 0{,}149 + \frac{1}{12}\left(1 + \frac{R_1}{R_2}\right)^2 - \left(\frac{1}{4} + \frac{3}{4}\frac{R_1}{R_2}\right) + \frac{1}{2}\left(\frac{R_1}{R_2}\right)^2\right]\right\} \qquad (10)$$

2.1. Problem statement and purpose of work

The dependence of $\delta_н$ on α_1 for different values of the parameter R_1 / R_2 is presented by a family of curves in Fig. 2. From these curves it can be seen that to ensure the partial relative error $\delta_н$ no more than 0.25% at α_1 less than 0.1, it is necessary that the ratio R_1 / R_2 ≤0.01.

To meet this requirement in the package of the device, the dependence of the resistance R2 on the frequency was experimentally determined (this resistance is nonlinear and frequency-dependent due to the specifics of the operation of the adopted ECV). Measurements are recommended to be carried out by gradually increasing the measured value to the limit value for the device under test, followed by a gradual decrease in it to a minimum. The increase and decrease of the measured value are carried out as many times as the measurements need to be made, each time fixing the readings of the investigated measuring device at the selected points of the scale.

According to the obtained values of R2, such values of R1 and C were selected, at which sufficiently small errors are combined with a sufficiently short measurement time [1].

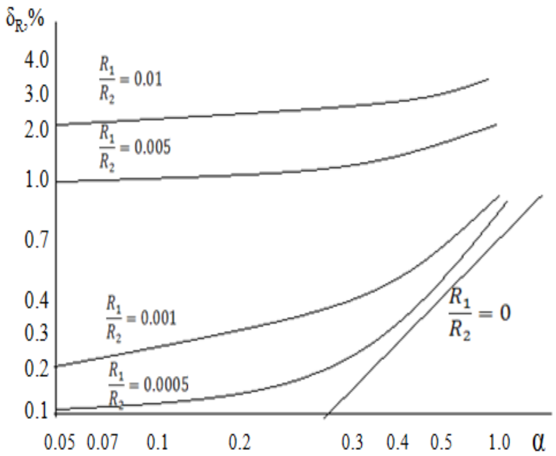

Figure 2: Dependence of δн on α1 for different values of the parameter R_1 / R_2

3. The influence of the key control unit and an electronic digital voltmeter on the device error can be divided into: the influence of the switching angle (or phase) of the control voltage; the influence of the cutoff angle θ of the control voltage and the influence of the pulse fronts that control the key.

a) The influence of the switching angle ψ is determined from consideration of the circuit in [1] at the input voltage $e = U_m \sin(\omega t + \psi)$ and for different values of the angle ψ. The experimental data and calculated values obtained by the described method are initial, allowing, through appropriate processing, to obtain the necessary information about the investigated measuring instrument. Mathematically, the problem is reduced to solving the difference equation following from the linear differential equation for the voltage u (t) on the capacitor of the circuit in [1] with a closed switch K

$$\tau \frac{du(t)}{dt} + u(t) = U_m \sin(\omega t + \psi). \qquad (11)$$

If we take into account the closure and opening of the circuit with the key K at the moments of time 0 and T / 2, then (11) turns into a difference equation of the form

$$U[n+1] - U[n]e^{-\alpha} = B\sin(\varphi - \psi)(1 - e^{-\alpha}) \quad (12)$$

where

$$\alpha = \frac{T}{2\tau};$$

$$B = \frac{U_m}{\sqrt{1 + \omega^2\tau^2}};$$

$$\varphi = arctg\omega\tau.$$

Solution (12) at the intervals of an open switch in a quasi-stationary mode (it is at these intervals that the voltage across the capacitor is measured with an electronic voltmeter) has the form

$$U_{vv\psi} = k_\psi cth\frac{\alpha}{2}, \quad (13)$$

where $k_\psi = B\sin(\varphi - \psi)$.

Partial relative error δ_ψ of the output voltage

$$\delta_\psi = \frac{U_{vv\psi} - U_{vv}}{U_{vv}} = -2\sin^2\frac{\psi}{2} - \frac{\alpha}{\pi}\sin\psi. \qquad (14)$$

As a result of determining the error δ_ψ according to this formula, are shown in Fig. 3 for two values α= 0.1 and 0.25.

b) The influence of the cutoff angle is determined according to the same initial equation as the influence of the switching angle ψ, with the difference that instead of the times of the key operation 0 and T / 2, it is necessary to calculate the circuit when the key is triggered at the moment $\left(\frac{\pi}{2\omega} - \frac{\theta}{\omega}\right)$ and $\left(\frac{\pi}{2\omega} + \frac{\theta}{\omega}\right)$

This somewhat complicates the compilation and solution of the difference equation, without fundamentally changing anything. Measurement errors from the influence of influencing factors are the components of the measurement errors, which are a consequence of the unaccounted influence of external factors on the measurement results.

The steady-state value of the voltage across the output capacitor in the measurement interval has the form

$$U_{vv\theta} =$$

$$= \frac{U_m}{\sqrt{1+\omega^2\tau^2}}\left(cos\varphi \cos\theta + sin\varphi\, sin\theta\, cth\frac{2\alpha\theta}{2\pi}\right). \quad (15)$$

The relative error δ_θ is equal to

$$\delta_\theta = \frac{\pi\alpha}{\pi^2+\alpha^2}\left[\frac{\alpha}{2}cos\theta + \frac{\pi}{2}\left(sin\theta cth\frac{\alpha\theta}{\pi} - cth\frac{\alpha}{2}\right)\right]. (16)$$

The results of calculating this error for several parameter values are shown in Fig. 3.

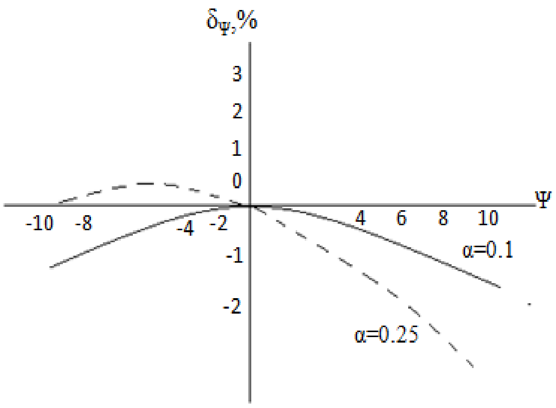

Figure 3: Results of calculating the uncertainty for several values

From the curves in Fig. 3 it can be seen that the moments of supply of the key control impulses have a significant effect on the conversion error. Physically, such a sharp influence on the error is quite natural, since the difference of these moments from the moments corresponding to the change in the sign of the measured voltage (the moments of the transition of the measured voltage through the zero level) directly changes not only the voltage across the capacitor when the switch is open, but also affects the process of changing the instantaneous capacitor voltage values when the switch is closed.

c) The influence of the pulses generated by the key control unit on the device error is also due to the finite value of the duration of the edges of these pulses (the influence of the amplitude of these pulses can be made small by choosing the correct key circuit, for example, with a six-diode key circuit).

Non-identical current-voltage characteristics of the key diodes, as well as non-identical shape of the front and rear the fronts of the control pulse, causes the appearance of switching bursts in the signal at the output of the switch. These bursts do not lend themselves to rigorous mathematical analysis, but are easily detected by an electronic oscilloscope. Due to the fact that switching bursts are frequency-independent, their effect is stronger at high frequencies of the measured voltage.

An experimental study of the device prototype showed that balancing the diode switch (by selecting silicon diodes and introducing a balancing resistance) and using powerful lamps in the output cathode follower of the control unit can easily achieve a short duration (<12 meters per second) and amplitude (<1 / 4Um) of these bursts. These measures, taken in the tested prototype of the device, ensured a negligible influence of the shape of the control pulses at all frequencies below 200 Hz.

1. To consider the influence of the key operation on the error, it is convenient to divide the key operation cycle into three stages: the key conducts, the key does not conduct, and the beak is "thrown over". The third state causes the just considered commutation bursts, and in the first two states an error may arise due to the finite (and not infinitely small or large) switch resistance, as well as due to the appearance of parasitic emf. or current at the output of the key.

In the considered device, the final resistance of the conducting switch, practically when using silicon diodes, can always be neglected in comparison with the resistance R1 of the integrating link, since the first resistance is of the order of several ohms, and the second - several hundred or thousands of kilo-ohms. The influence of the final resistance of the open key Rk can be considered in a manner similar to the pleasant one when considering the influence of the resistance R2. In this case, the steady-state value of the voltage at the output capacitor in the measurement interval has the form

$$U_{vvk} = k_1\frac{1+e^{-\alpha_1}}{1-e^{-\alpha_0}} - k_2 \cdot e^{-\alpha_1}\frac{1+e^{-\alpha_2}}{1-e^{-\alpha_0}}, \quad (17)$$

where $k_{1,2} = \frac{\pm U_m}{\sqrt{1+\omega^2\tau_{1,2}^2}}$;

$$\alpha_{1,2} = \frac{T}{2\tau_{1,2}};$$

$$\alpha_0 = \alpha_1 + \alpha_2; \alpha_2 = \alpha_1\frac{R_1}{R_K},$$

and the conversion error is expressed by the formula

$$\delta_k = \frac{U_{vv}-U_{vv}}{U_{yct}} = -1 + \frac{1-e^{-\alpha_1}}{1-e^{-\alpha_0}} - \frac{k_2}{k_1}e^{-\alpha_1}\frac{(1-e^{-\alpha_1})(1+e^{-\alpha_2})}{(1-e^{-\alpha_0})(1+e^{-\alpha_1})}. \quad (18)$$

Expression (18) with a sufficient degree of accuracy for real values of the parameters α and R_1 / R_K is approximated by the expression

$$\delta_k \cong \frac{R_1}{R_K}. \quad (19)$$

It is clear from (19) that this error when using selected silicon diodes can be small, so that the resistance of the open switch does not affect the overall error of the device.

3. Conclusions

From the above, the following conclusions can be drawn. Equivalent emf a closed switch can have a significant impact, since it is directly added to the measured voltage. The task of balancing the key circuit is to get rid of this emf. Theoretically, this issue does not lend itself to accurate analysis due to the instability and nonlinearity of the current-voltage characteristics of the diodes, but an experimental study of this effect is not difficult. Experiments have shown that daily changes in the equivalent emf the key does not exceed 0.5 mV, and an increase in temperature by 40 ° C (from the value of 200 ° C) causes an emf. not exceeding 5mV. Considering that these switches are intended for use in a device in which the highest value of the measured voltage at the switch output is 10V, then it is clear that such small changes in the equivalent emf. closed key are perfectly valid.

In the open state, a possible source of instrument error is the equivalent output current of a non-conductive switch. However, it can also be brought to a negligible value (in the breadboard, the value of this equivalent current was less than 10-12A). The use of unmatched silicon diodes or diodes of other types limits the upper limit of the value of the resistance R1 of the integrating element. Verification of measuring instruments should be carried out under normal operating conditions. The operating conditions of operation must be observed in the practical use of measuring instruments. Additional errors arising when operating conditions differ from normal ones are usually expressed in fractions or multiples of the basic error. The ratios used to assess additional errors are given in the operating instructions for specific types of measuring instruments.

The carried out consideration of various sources of the device hardware errors (the errors of the electronic digital voltmeter were not considered, since their influence is clear, and they are usually very small) showed that it is easy to fulfill the conditions under which the partial components of the total device error will be small enough and even with a simple arithmetic summation, the total error will not exceed 0.5%.

4. References

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