Oleksandra HOTRA [1], **Oksana BOJKO** [2], **Jacek MAJEWSKI** [1]
[1] POLITECHNIKA LUBELSKA, WYDZIAŁ ELEKTROTECHNIKI I INFORMATYKI
[2] DANYLO HALYTSKY NATIONAL MEDICAL UNIVERSITY OF LVIV, MEDICAL INFORMATICS DEPARTMENT

Influence of methods for noise reduction on dynamic characteristics of active resistance imitators

Prof. Oleksandra HOTRA

In 1989 she graduated in electronic engineering from Lviv Polytechnical National University, Department of Semiconductor Electronics. In 1996 she received Ph.D. degree from Institute of Physics of Ukrainian Accademy of Sciences in Kiev. She habilitated in thermal measurement from Lviv Polytechnical National University in 2002. Since 2007 she is Professor of Informatics. Her fields of interests are sensors of physical quantities based on integrated optics and electronics, liquid crystals and liquid crystal devices.

e-mail: o.hotra@pollub.pl

Ph.D. Jacek MAJEWSKI

He received the M.S. degree firstly in mechanical engineering, and secondly in electrical engineering, in 1983 and 1989, respectively, and Ph.D. degree in electrical engineering in 1999, from the Lublin University of Technology. His special fields are: sensors, digital measuring instruments and fundamentals of metrology. He is working in Lublin University of Technology, Faculty of Electrical Engineering and Computer Science, Chair of Automation and Metrology.

e-mail: j.majewski@pollub.pl

Ph.D. Oksana BOJKO

She graduated from the Faculty of Applied Mathematics, Lviv Polytechnic State University in 1998. Ph.D. from Lviv Polytechnic National University with the thesis "Code-controlled resistance measures for measuring instrument metrological assurance in industrial conditions" in 2004. Her scientific interests include precision calibrators of voltage, current and resistance, and mathematical modeling. She is the author of 25 scientific works and inventions.

e-mail: oxana_bojko@ukr.net

Abstract

The influence of normal mode noise on the accuracy of transmission of standard resistance units using active resistance imitators is analysed. Also the influence of selected methods of noise attenuation on dynamic characteristics of active resistance imitators is investigated. The dynamic errors and transition time of input signals are determined. The investigation results show that the optimisation of the noise reduction and of the dynamic characteristics of active resistance imitators under real industrial conditions is possible by the appropriate selection of frequency-dependent elements.

Keywords: active resistance imitators, noise, frequency characteristics, transition time, dynamic errors of resistance imitation.

Wpływ metod tłumienia zakłóceń na charakterystyki dynamiczne aktywnych imitatorów rezystancji

Streszczenie

Przeanalizowano wpływ zakłóceń równoległych na dokładność przekazywania jednostkowej miary wzorca rezystancji za pomocą aktywnych imitatorów rezystancji. Przebadano wpływ wybranych metod tłumienia zakłóceń na charakterystyki dynamiczne aktywnych imitatorów rezystancji. Wyznaczono błędy dynamiczne oraz czas ustalania wartości sygnałów wejściowych. Wyniki badań wykazały, że możliwa jest optymalizacja odporności na zakłócenia i charakterystyk dynamicznych aktywnych imitatorów rezystancji w roboczych warunkach eksploatacji poprzez odpowiedni dobór elementów zależnych od częstotliwości.

Słowa kluczowe: aktywne imitatory rezystancji, zakłócenia, charakterystyki częstotliwościowe, czas ustalania, błędy dynamiczne imitowania rezystancji.

1. Introduction

The basis for keeping high metrological reliability of measuring instruments is periodical checking of metrological characteristics in their working conditions. The traditional method of verification is realised by dismantling the instruments from technological objects and transporting them to conditioning places where normal conditions for the verification are created. That way of verification is characterised by both organisational and technical inconveniences, as well as financial expenses. Moreover, the verification of measuring instruments in such "purified" conditions does not allow determining correctly all metrological properties which can appear in working conditions and revealing (and then taking into account) all the factors causing errors.

There are a lot of industrial plants where both dismantling the measuring instruments and setting the measures of standard quantities for verification directly at the inputs of measuring devices − or at the inputs of measuring channels – is impossible. Then the problem of the transmission of standard measure units over distance − in particular for resistance standards − emerges. Thus, the accuracy of transmitting the resistance standard units over considerable distances is related to overcoming the influence of bus connection resistances and external noises. In such conditions it is reasonable to build the measures of resistance based on active resistance imitators (ARIs) [1]. In industrial working conditions, both internal and external electric circuits of active resistance imitators are exposed to noise, which changes the value of the voltage between the points of the resistance imitation. The noise interferes in the measuring circuits in which ARIs are plugged, mainly through the parasite galvanic connections between the source of noise and the measuring circuits, as well as the result of electromagnetic and electrostatic induction on a transmission line and on some areas of electric circuits of ARIs. The increase in power consumption by industrial equipment − both electromechanical and technological − causes the sharp increase in the intensity of industrial noise [2, 3]. The noise involves a growth of the resistance imitation error. Thus, the error can exceed not only the value of the acceptable basic error, but sometimes the value of the imitated resistance [4].

The efforts to reduce the impact of noise on the error of resistance restoration worsen both the frequency and transfer characteristics of ARIs. That implies that research on methods for increasing the noise reduction and its impact on dynamic characteristics of ARIs are essential.

2. Methods for reducing the impact of normal mode noise

In [5] it is shown that in order to reduce the impact of normal mode noise in a four-wire ARI, it is necessary to try to equalize the noise in transmission lines. Equalization of noise in all transmission lines can be obtained by means of the equality of parameters of galvanic connections between the source of noise and separate transmission lines. For equalization of parameters of galvanic connections, the well-known constructive methods (screening, mesh shield wiring of transmission lines, grounding, etc.) are applied. However, they do not allow complete eliminating the impact of noise on signals in the measuring circuits [6]. For reducing the impact of noise, also structural methods are used [4, 7]. Since common methods for noise reduction used during voltage measurement cannot be applied to ARIs, some special methods for reduction of the noise impact on the resistance imitation error are needed.

The structural scheme of the ARI with compensation of the impact of normal mode noise in all transmission lines is shown in Fig. 1.

For equalization of the noise in the first and second transmission lines, the circuit of forming a compensative current (CFCC), built on the operational amplifier DA2, with the resistors R_1, R_2 and R_3 in feedback loops is incorporated. Then, the ARI static characteristic function is described by

$$R_{im} = R_0\mu + \frac{e_{z4} - e_{z2}}{I_{in}} + \left(\frac{e_{z2} - e_{z1}}{I_{in}} + \frac{I_c R_0}{I_{in}}\right)\mu + \frac{e_{z3}}{kI_{in}}, \quad (1)$$

where e_{z1}, e_{z2}, e_{z3}, e_{z4} are the values of the noise voltage in corresponding lines; μ is the gain factor of a code-controlled voltage divider CCD; I_{in} is the input current value; I_c is the compensative current value; R_0 is the standard resistor resistance value; k is the amplification factor of the operational amplifier DA3.

When $R_0R_2 = R_1R_3$, the CFCC forms the current

$$I_c = \frac{e_{z1} - e_{z2}}{R_0}. \quad (2)$$

Assuming that the error of forming the compensative current is negligible, the transform function is found as

$$R_{im} = R_0\mu + \frac{e_{z4} - e_{z2}}{I_{in}} + \frac{e_{z3}}{kI_{in}}. \quad (3)$$

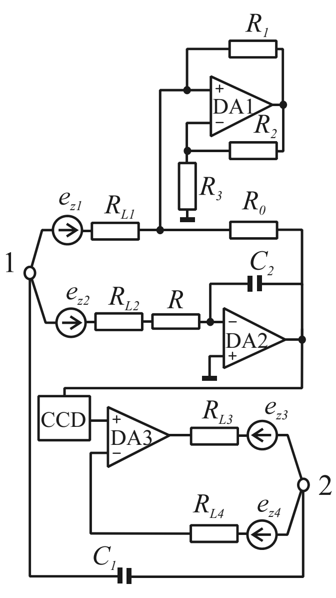

Fig. 1. The equivalent structural scheme of the ARI with compensation of normal mode noise

Rys. 1. Strukturalny schemat zastępczy aktywnego imitatora rezystancji z kompensacją wpływu zakłóceń równoległych

The equalizing of the noise in the second and fourth transmission lines is achieved by inserting additional capacitive connections which provide equal potentials of the variable component both in the second and fourth line. The noise in the third line is reduced due to the feedback of the output amplifier, placed in the circuit containing this line. So, the efficiency of noise attenuation depends only on the amplification factor of the operational amplifier DA3. To reduce the capacity of C_2 in series with the resistance of link R_{L2}, the resistor R is added.

The equivalent value of noise between the points 1 and 2 − when neglecting the errors caused by limitation of the amplification factor of op-amps and forming of I_c − can be expressed as

$$U_{12} = (e_{z4} - e_{z2})\left(1 - \frac{R_0(R_{L2} + R)}{R_0(R_{L2} + R) - \frac{1}{\omega C_1}\frac{1}{\omega C_2} - j\frac{R_0}{\omega C_1}}\right), \quad (4)$$

where ω denotes radian frequency.

The attenuation factor of noise influence (in decibels) is equal:

$$K_n = 20\lg\left|\frac{\hat{U}_{12}}{U_{12}}\right|, \quad (5)$$

where $\hat{U}_{12}$ is the maximal value of noise between the points 1 and 2.

After substituting (4) and other relations into (5), the following formula is obtained:

$$K_n = 20\lg\frac{\left[R_0(R_{L2} + R) - \frac{1}{\omega^2 C_1 C_2}\right]^2 + \left(\frac{R_0}{\omega C_1}\right)^2}{\frac{1}{\omega C_1}\sqrt{\left(\frac{1}{\omega^3 C_1 C_2^2} + \frac{R_0^2}{\omega C_1} - \frac{R_0(R_{L2} + R)}{\omega C_2}\right)^2 + [R_0^2(R_{L2} + R)]^2}} \quad (6)$$

The attenuation factor of noise depends on the values of R_0, R, C_1 and C_2. The investigation results show that the noise reduction factor increases by 20 dB when the capacity C_1 value or the resistance R value increases by one decimal order. The increase in the values of C_1 and R is limited firstly by the input signal transition time, secondly by the op-amp input resistance and finally by the capacitor size and residual resistance. The optimal value of capacity C_2 is 10 µF.

3. Analysis of ARI dynamic properties

For the purpose of analysing how frequency-dependent elements influence the dynamic errors of resistance imitation, the imitated resistance as a frequency-dependent function of the input signal is determined:

$$R_{im}(\omega) = \frac{\sqrt{\frac{1}{\omega^2 C_1^2}\left(R_0R_2 + \frac{\mu}{\omega^2 C_2^2}\right)^2 + \left(R_0R_2^2 + \frac{R_0\mu - R_2}{\omega^2 C_1 C_2} - \frac{R_0\mu^2}{\omega^2 C_2^2}\right)^2}}{\left[R_0^2\left(\frac{1}{\omega C_1} + \frac{\mu}{\omega C_2}\right)^2 + \left(R_0R_2 - \frac{1}{\omega^2 C_1 C_2}\right)^2\right]\frac{\omega C_1}{R_0}} \quad (7)$$

where $R_2 = R_{L2} + R$.

The values of capacities C_1 and C_2, as well as the resistance R value affect the error of resistance imitation. As shown in Fig. 2, the decrease in both C_2 and R extends the frequency range of the resistance imitation. The value of C_1 does not exert influence on the frequency range.

The input signal transition time is a distinctive feature for operation of ARI. The time-domain analysis of the ARI characteristic can be made by means of the operational method applied to calculations of transient performance.

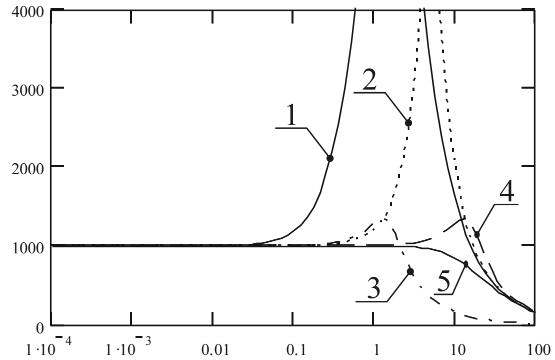

Fig. 2. Dependence of the imitated resistance value on frequency: 1 – R=10 kΩ, C_1=10 μF, C_2=100 μF; 2 – R=10 kΩ, C_1=10 μF, C_2=10 μF; 3 – R=10 kΩ, C_1=100 μF, C_2=10 μF; 4 - R=10 kΩ, C_1=10 μF, C_2=1 μF; 5 – R=1 kΩ, C_1=10 μF, C_2=10 μF

Rys. 2. Zależność wartości imitowanej rezystancji od częstotliwości

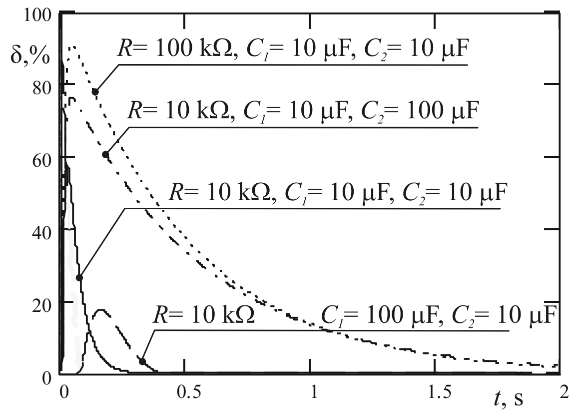

Fig. 3. Relative dynamic error of resistance imitation

Rys. 3. Błąd względny dynamiczny imitowania rezystancji

The formula describing the voltage between the points of resistance imitation 1 and 2 after switching the ARI at the starting moment t=0 − under zero initial conditions − to the source of measure of 1 volt (with output resistance R_{out}) can be expressed in operational form as:

$$U(p)=\frac{R_{im}(p)}{p\left[R_{out}+R_{im}(p)\right]}, \tag{8}$$

where R_{im} is equal:

$$R_{im}(p)=\frac{R_0\left(R_{L2}+R\right)C_2p+R_0\mu}{R_0\left(R_{L2}+R\right)C_1C_2p^2+R_0\left(C_1\mu+C_2\right)p+1}. \tag{9}$$

To return to the time-domain function, the inverse Laplace transformation is applied:

$$U(t)=L^{-1}\left[U(p)\right]. \tag{10}$$

The relative dynamic error of resistance imitation is given by:

$$\delta Z(t)=\frac{U(t)/I_{in}-U_n(t)/I_{in}}{U_n(t)/I_{in}}=\frac{U(t)-U_n(t)}{U_n(t)}. \tag{11}$$

where $U_n(t)$ is the nominal value of the output voltage between the points of resistance imitation.

Using *MathCad* package, the graph of the relative dynamic error δ of resistance imitation versus time t (Fig. 3), and the graphs of the output signal transition time t_t versus R and C_1 (Fig. 4) and C_2 (Fig. 5) were obtained.

The analysis of those graphs shows that the transition time t_t depends on R and C_2, and practically is independent of C_1. The transition time t_t duration does not exceed 1 s if the values of R and C_2 do not exceed 10 kΩ and 10 μF, respectively. If R or C_2 increase tenfold, the transition time t_t will exceed 4 s.

Moreover, the ARI operation was simulated using program *Electronics Workbench* . In that investigation a rectangular pulse train (amplitude 1V, the generator output resistance 1kΩ) was delivered to the ARI output which imitated the value 1 kΩ, and transition time was estimated. The oscillograms of transition processes at the ARI output for different values of R, C_1 and C_2 are shown in Fig. 6.

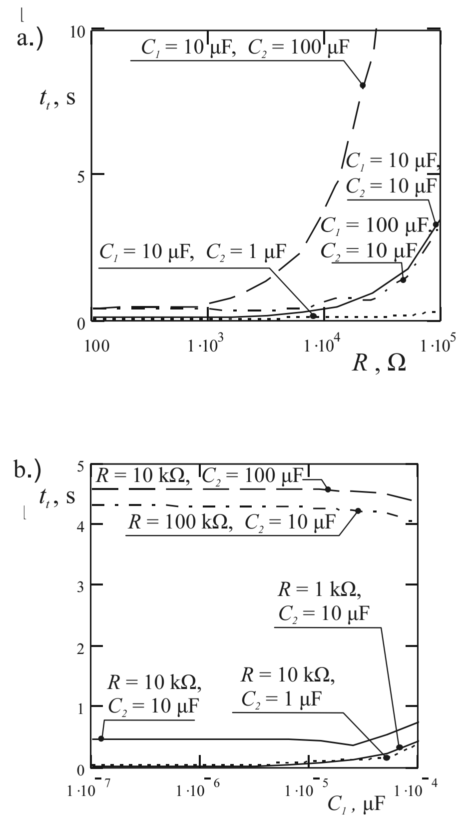

Fig. 4. Dependence of the output signal transition time on: a) the value of resistance R; b) the value of capacity C_1

Rys. 4. Zależność czasu trwania stanu przejściowego od: a) wartości rezystancji R, b) wartości pojemności C_1

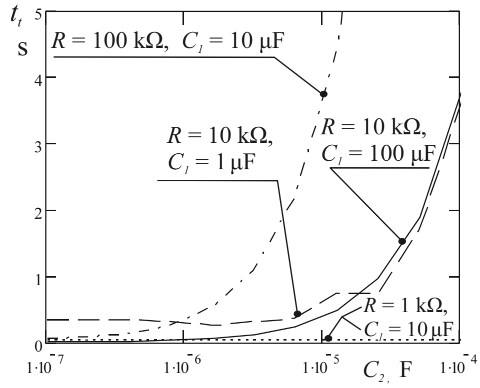

Fig. 5. Dependences of the input signal transition time on the value of capacity C_2

Rys. 5. Zależność czasu trwania stanu przejściowego od wartości pojemności C_2

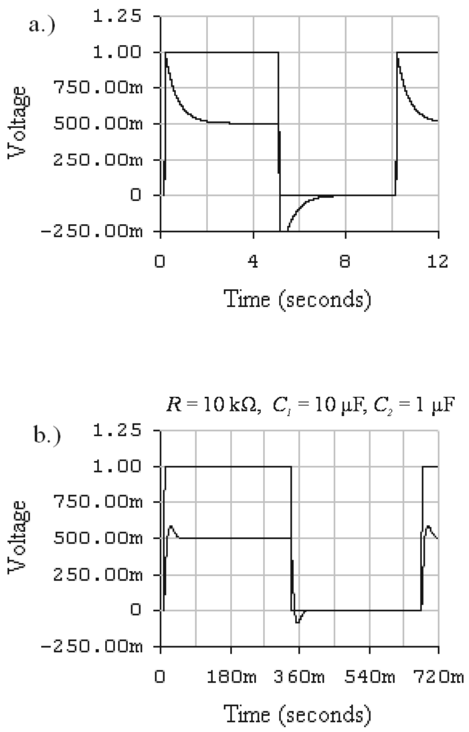

Fig. 6. The output signal of ARI vs. time
Rys. 6. Zmienność sygnału wyjściowego imitatora rezystancji w czasie

The obtained results demonstrate that the transient process is mostly influenced by *R* and C_2; an increase in both *R* and C_2 involves an increase in the ARI output signal transition time. The change in value of C_1 involves only minute changes in the transient process, especially when $C_1 \leq 10\mu F$. The simulation results agree well with the modelled ones.

4. Conclusions

The noise can considerably affect the resistance error in ARI. Using the circuit forming a compensative current and additional capacitive connections, it is achievable to reduce the noise in all transmission lines of ARI. It is possible to make a trade-off between the noise reduction and the ARI dynamic characteristics in specific industrial conditions by matching the capacitors C_1, C_2 and additional resistor *R*. For optimisation of ARI characteristics (its error of resistance imitation, noise reduction factor, frequency range, input signal transition time) it is recommended to apply frequency-dependent elements which can be adjusted according to real conditions of exploitation.

5. References

[1] О.Бойко, П.Столярчук, В.Яцук: Переносна багатозначна міра опору. Вимірювальна техніка та метрологія, №54, 1999.
[2] Павленко В.А. Электрические системы регулирования с сигналом связи постоянного тока. Москва: Энергия, 1971.
[3] Поліщук Є.С., Дороговець М.М., Яцук В.О. та ін. Метрологія та вимірювальна техніка / За ред. проф. Є.С.Поліщука. – Львів: Видавництво "Бескид Біт", 2003.
[4] Дороговець М., Мотало В., Стадник Б. та ін. Основи метрології та вимірювальної техніки / Т.2. Вимірювальна техніка. За ред. проф. Б.Стадника. – Львів: Видавництво НУ "Львівська політехніка", Львів, 2005.
[5] Бойко О. Вплив завад у чотирипровідних активних імітаторах опору // Вимірювальна техніка та метрологія. №62, Львів, 2003.
[6] Серьезнов А.Н., Цапенко М.П. Методы уменьшения влияния помех в термометрических цепях. Москва: "Энергия", 1968.
[7] Малиновский В.И. Цифровые вольтметры интегрирующего типа (Обзор). // Приборы и системы управления. №2, 1973.

Artykuł recenzowany