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THE STUDY OF ERRORS OF RESISTANCE TRANSFORMATION OF RESISTIVE SENSORS, WHILE PROVIDING THE QUASI-INVARIANCE TO THE RESISTANCE OF THE CABLE INSULATION OF THE COMMUNICATION CHANNEL

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Abstract. In the present article the studies of errors of resistance transfomation of resistive sensors ensuring the quasi-invariance to the resistance of cable insulation of the low conductivity measurement systems (MS) are considered. Open structure of the resistance transducer of resistive sensors (CRRS) provides the invariance to change of parameters of the communication channel (CC). This ensures conducting of the operation in hardest conditions, such as the measurement at the depth under conditions of high stationary temperatures.

Keywords: measurement system, a communication channel, open-loop structure, the resistance transformation of the resistive sensors, quasi-invariance.

Introduction

In various fields of oil and gas industry, including the depth measurements, collection and processing of the information received by resistive sensors which have as informative parameter the active resistance (resistance thermals, hot-wire sensors with direct and indirect heating, strain gages, and others, based on a variety of physical effects) do not loose the relevance. Resistive sensors have good metrological characteristics - accuracy, stability, reliability and durability, and converters of resistance can have quite simple block diagrams. Solution of a number problems associated with the conversion of different parameters requires new MS with high accuracy and reliability.

The sensors can be placed in the immediate vicinity of the displaying, recording or processing of information or, more commonly, remote from it. In the latter case CRRS contain CC and can be elements of MS as a combination of functionally integrated measuring instruments and accessories that are characterized by the presence of one or more measurement channels. In case of wire channel in the form of a line of small length (tens, sometimes hundreds of meters), according to the established tradition, it is a measurement of distance, and in its greater length it is the telemetry, which for example, takes place in measurements in wells. Therefore, the search for invariance, i.e. independence of the results of the transformation from non-informative parameters [1], in particular, the parameters of the CC (active resistance communication line – ARL, reduction of the insulation resistance of wires - IRW, and a parameter caused by the influence of the CC stationary electric fields, such as EMF polarization of rocks E_p, induced on armor of single core armored wire line during measurements in open holes - SEF), with a minimum number of passive elements in transforming area of measurement, it is inseparable from the tasks related to the development of systems CRRS with RS. In this case, the functional substitutability of transduction elements in the area of measurement (TEAM) and recalculating of the transformation equation of informative parameters without a radical changing the structure of MS due to the introduction of the controller to control the measuring process is a rational concept [2].

Evaluation of methodological error, introduced while ensuring quasi-invariance to reducing IRW

Let us refer to the evaluation of the methodological error that occurs when providing quasi-invariance to reducing IRW. The nature of this error is associated with the assumption of the concentrated nature of the leak, the coordinate of the localization of θ in the general case is unknown [3]. θ at values equal to 0 and 1, there are extreme cases where the leak is either in the transformation zone, or in the immediate vicinity of the processing device (PD). Therefore, in the real transformation algorithm the optimal, in the point of view of exception of extreme cases, is the value of θ = 0,5. By using the terms listed in table 2.2, 2.3 [4], we can define the maximum methodological errors for θ = 0,5 and several values of IRW, as well as errors caused by the influence of unreported leaks. Comparing the obtained value of the error with a maximum permissible error of the transformation of sensor resistance, we can determine the limits of applicability of the conversion method of the sensor resistance in each particular case.

The effectiveness of the proposed methods of reduction of the impact of the errors caused by-leakage in the IRW to be first considered on the example of CRRS while ensuring simultaneous invariance to ARL, where ECC is T-equivalent communication channel (figure 1).

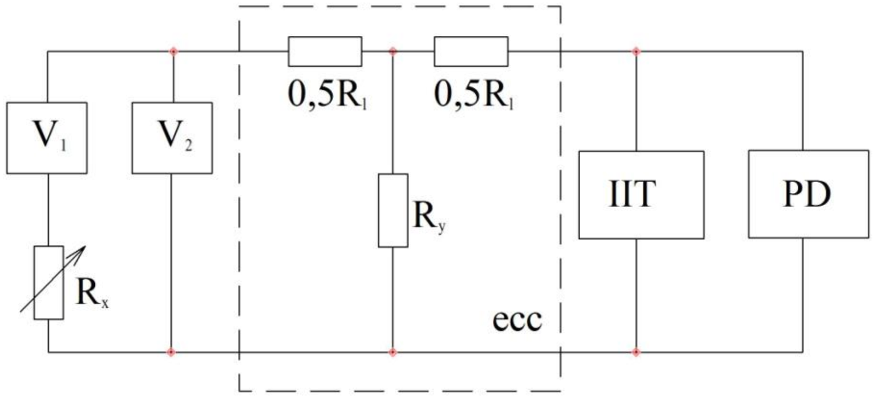

Figure 1. Block diagram CRRS with quasi-invariance to reduce IRW
and invariance to ARL

Here as a TEAM the non-linear elements with a working section of the current-voltage characteristics can be used, parallel to the current V_1, V_2. The cycle includes the measurement of the three cycles (steps) of the input voltage and the processing unit at θ = 0,5 are (table 2.2) [4]:

$$U_1 = I\cdot(0{,}5\cdot R_l + R_y);$$
$$U_2 = \frac{(k\cdot I\cdot R_y - U_{c1})\cdot(0{,}5\cdot R_l + R_x)}{R_y + 0{,}5\cdot R_l + R_x} + 0{,}5\cdot k\cdot I\cdot R_l + U_{c1}; \quad (1)$$
$$U_3 = -\left[\frac{0{,}5\cdot R_l\cdot(k\cdot I\cdot R_y - U_{c2})}{R_y + 0{,}5\cdot R_l} + 0{,}5\cdot k\cdot I\cdot R_l + U_{c2}\right].$$

Determining the voltages $U_1 \div U_3$ and substituting them into the equation of the transformation of sensor resistance for the extreme values of the coordinate of the location of leakage, for example, for θ = 0, we obtain:

$$R'_x = \frac{U_1\cdot(U_2 - U_{c1}) - I\cdot R_l\cdot(k\cdot U_1 + U_2 - U_{c1} - k\cdot I\cdot R_l)}{I\cdot(k\cdot U_1 - U_2)}, \quad (2)$$

where $R_l = \dfrac{U_3 + U_{c2}}{k\cdot I}$.

It is possible to determine the maximum conversion error

$$\gamma_m = \frac{\Delta}{\Delta R_{xm}}\cdot 100\%, \quad (3)$$

where $\Delta = R_x - R'_x$.

To assess the degree of effectiveness of the proposed method of minimization of an additional error caused by the decrease in IRW, we can compare a methodical transformation error with an error of neglecting the influence of leakage while providing invariance to ARL

$$\gamma_y = \frac{\Delta'}{\Delta R_{xm}} \cdot 100\%, \qquad (4)$$

where $\Delta' = R_x - R''_x$.

The converted value of resistance R''_x, determined without the influence of leakage can be calculated by the formula

$$R''_x = \frac{U'_2 + U'_3 + U_{c2} - U_{c1}}{k \cdot I}, \qquad (5)$$

where $U'_2 = U_2, U'_3 = U_3$.

Consider a numerical example, in which the value of the quantities involved in the calculation formulas corresponds to the actual parameter values of the instruments for deep measurements. For example, reducing leakage resistance up to 10^6 Om and less – $5x10^4$ Om, for R_{x0} = 1000 Om, ΔR_{xm} = 500 Om, R_l = 100 Om, I = 10^{-3} A, K = 10 and U_{c1}=U_{c2} = 8 V, the reduced methodological error is 0,03% and 0,57% respectively. The error caused by the neglect of the effects of leakage, will be with 0,72% and 13,94%, exceeding by more than an order of magnitude a methodical error in the entire range of decreasing resistance of the leak (table 1). Combined plots of the γ_m = f1 (R_y) and γ_y`= f2 (R_y), illustrated by the above example, are shown in figure 2.

Let us now regard CRRS ensuring quasi-invariance to reducing IRW while achieving simultaneous invariance to ARL and SEF (figure 3), which is the implementation of the method, illustrated by the scheme shown in figure 2.27 [4].

Here the source of IIT produces four rectangular impulses, and the corresponding passages of the input voltage PD at θ = 0,5 are written in the form (table 2.3) [4].

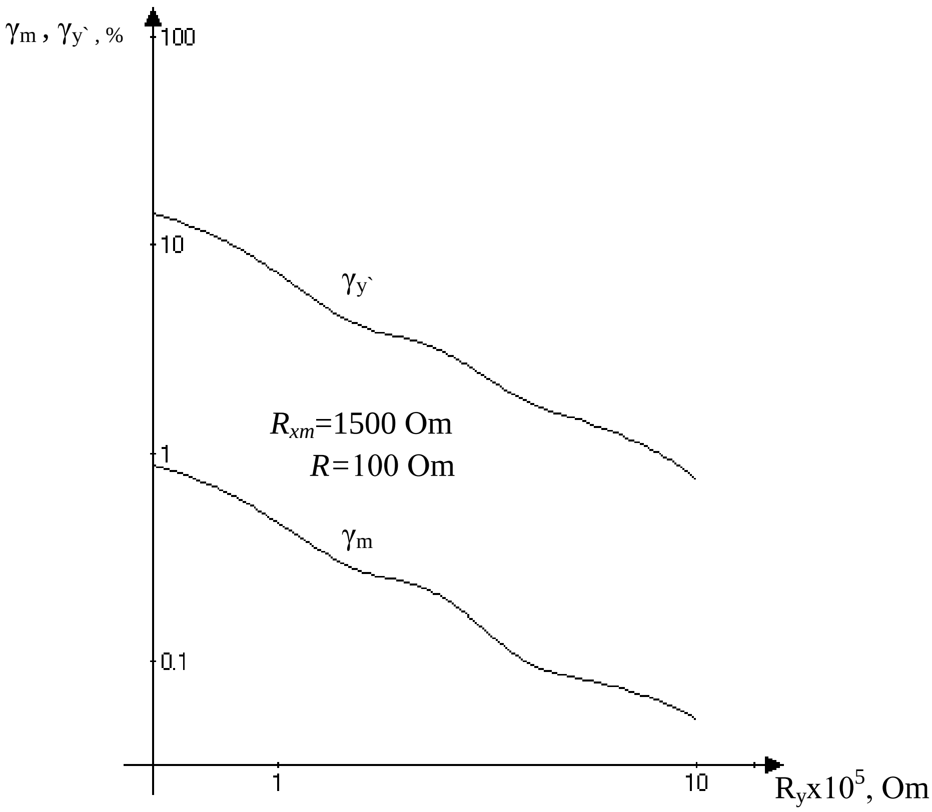

Figure 2. Graphs of $\gamma_m = f1(R_y)$, γ_y`$= f2(R_y)$ for CRRS with minimization of the impact of ARL and IRW

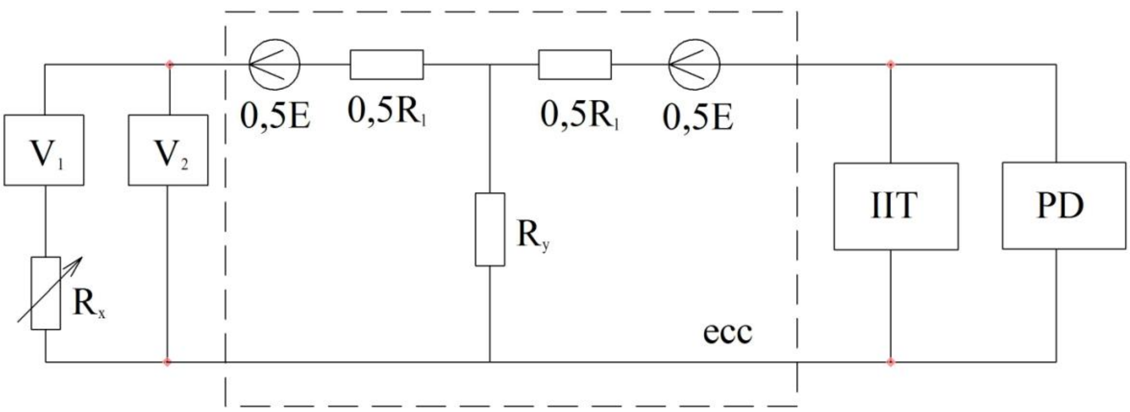

Figure 3. Block diagram of a quasi-invariance CRRS reduce IRW and invariance to ARL and SEF

$$
\begin{aligned}
&U_1 = I\cdot(0{,}5\cdot R_l + R_y) + 0{,}5\cdot E;\\
&U_2 = \frac{\left[k\cdot I\cdot R_y - (U_{c1} + 0{,}5\cdot E)\right]\cdot(0{,}5\cdot R_l + R_x) + (R_y + 0{,}5\cdot R_l + R_x)\cdot(0{,}5\cdot k\cdot I\cdot R_l + U_{c1} + E)}{R_y + 0{,}5\cdot R_l + R_x};\\
&U_3 = -\frac{\left[k\cdot I\cdot R_y - (U_{c2} - 0{,}5\cdot E)\right]\cdot 0{,}5\cdot R_l + (R_y + 0{,}5\cdot R_l)\cdot(0{,}5\cdot k\cdot I\cdot R_l + U_{c2} - E)}{R_y + 0{,}5\cdot R_l};\\
&U_4 = -\frac{\left[k'\cdot I\cdot R_y - (U_{c2} - 0{,}5\cdot E)\right]\cdot 0{,}5\cdot R_l + (R_y + 0{,}5\cdot R_l)\cdot(0{,}5\cdot k'\cdot I\cdot R_l + U_{c2} - E)}{R_y + 0{,}5\cdot R_l}.
\end{aligned}
\qquad (6)
$$

Substitution of values of voltage $U_1 \div U_4$ in transformation equation of the resistance sensor for extreme values of the coordinate of location of leakage, for example, $\theta = 0$

$$
R'_x = \frac{\left[U_1 - (I\cdot R_l + E)\right]\cdot(k\cdot I\cdot R_l + E - A)}{I\cdot\left[B - (k-1)\cdot E\right]}, \qquad (7)
$$

where

$$
\begin{aligned}
&R_l = \frac{E - C}{k\times I}; E = \frac{k'\times C - k\times L}{k' - k}; A = U_2 - U_{c1};\\
&B = k\times U_1 - U_2; C = U_3 + U_{c2}; L = U_4 + U_{c2},
\end{aligned}
$$

determine the maximum error of the reduced methodical transformation, the kind of which coincides with the formula (3).

Comparison of a methodological error with an error that occurs with change of the ARL, as in the example, which uses the values of the previous case, and, in addition, taking *E* = 0,5 V, which corresponds to the real conditions of the measurements in non-cased wells using single-core armored cable [5], gives the following results: with decreasing the leakage resistance in the range of $10^6 \div 5\text{x}10^4$ Om. The above methodological error is 0,052% and 0,87%, while the error caused by the changes only of ARL, will be with 19,26% and 5,92%, which in the first case exceeds the error of the method in 370,4 times (Table1).

Table 1

R_y, Om	θ=0,5				R_{xm} at θ=0, Om	Δ, Om	γ_m %	γ_y %	γ_y / γ_m	$\gamma_{y'}$ %	γ'_y / γ_m
	U_1, V	U_2, V	U3, V	U4, V							
10^6	1000,3	24,46	-8,50	-9,0	1499,74	0,26	0,052	19,26	370,4	0,74	14,2
$5\text{x}10^5$	500,3	24,42	-8,50	-9,0	1499,58	0,42	0,084	18,54	220,7	1,48	17,6
$3\text{x}10^5$	300,3	24,37	-8,50	-9,0	1499,24	0,76	0,15	17,56	117,1	2,44	16,3
$2\text{x}10^5$	200,3	24,31	-8,50	-9,0	1498,82	1,18	0,24	16,34	68,1	3,66	15,2
10^5	100,3	24,13	-8,50	-9,0	1497,71	2,29	0,46	12,74	27,7	7,26	15,8
$5\text{x}10^4$	50,3	23,78	-8,49	-8,9	1495,67	4,33	0,87	5,92	6,8	14,08	16,2

If we compare the methodological error with an error that occurs when registered ARL and SEF when the sensor resistance is calculated by the formula (table 2.4) [4]

$$R''_x = \frac{U_2 + U_3 - U_{c2} - U_{c1} - 2 \cdot E}{k \cdot I}; \quad (8)$$

Where $E = \frac{k' \cdot (U_3 + U_{c2}) - k \cdot (U_4 + U_{c2})}{k' - k}$,

then for the same, as in the previous case, changes of the leakage resistance, the reduced error exceeds the methodical one for more than an order of magnitude (тable 1). The graphs of the respective dependencies, illustrating considered numerical examples are shown in Figure 4.

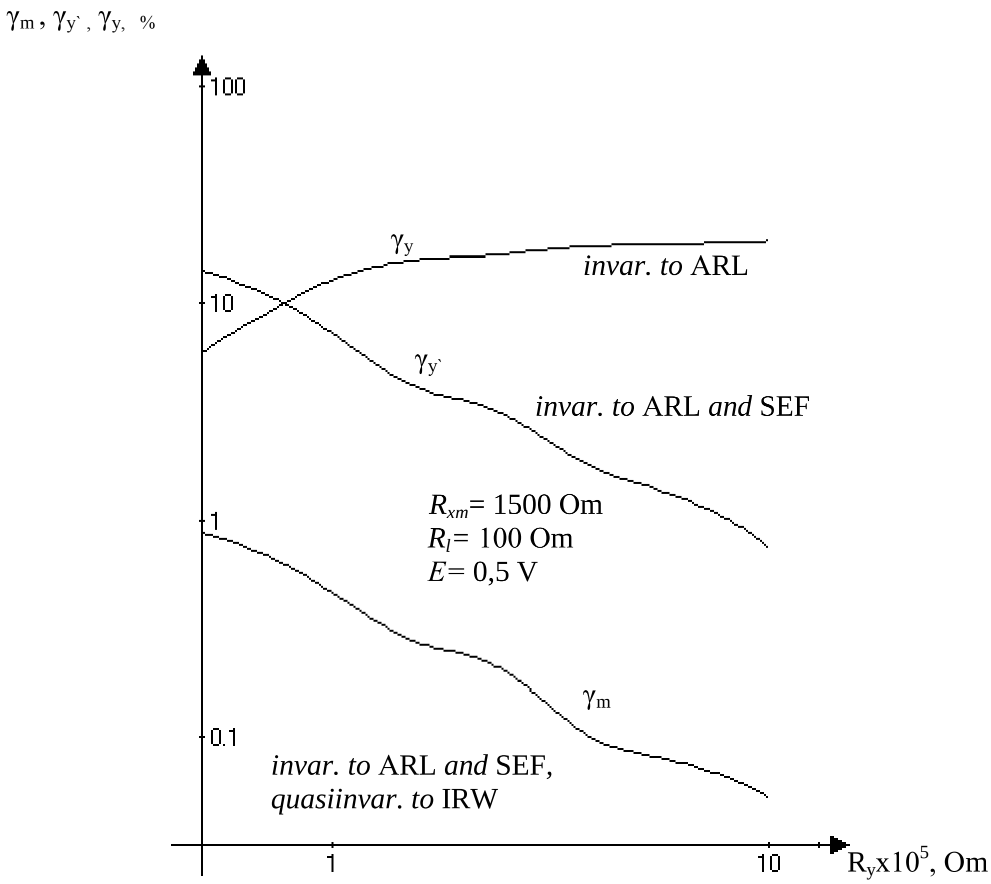

Figure 4. Graphs of γ_m = f_1'(R_y), γ_y = f_2'(R_y), $\gamma_{y`}$ = f_3'(R_y) for CRRS minimizing the impact of ARL, IRW and SEF

Referring to the invariance of error, which occurs when the reduction is accompanied by changing the value of IRW ARL. When reducing the ARL, a partial compensation of total deviation from ARL and IRW, due to the same sign of the increments produced by currents in the branching of the leak. If the ARL is increased, for example, that there is an increase in the temperature of the environment and with the strain effect, the signs of the increments are opposite and non-invariance of the total error increases slightly compared to the additional error caused by the decrease only in IRW. Indeed, by increasing the nominal of 100 Om, ARL values by 50%, accompanied by a decrease of IRW to 10^5 Om, increments for the sensor resistance at 50 Om, 500 Om, from (3.23) we see that the increase in overall accuracy invariance does not exceed 0,09% (тable 2).

Table 2

R_y, Om	γ_y, % at R_l=150 Om	
	R_0=100 Om ΔR_{xm} =50 Om	R_0=1000 Om ΔR_{xm} =500 Om
10^7	0,004	0,026
$5x10^6$	0,008	0,052
10^6	0,040	0,260
$5x10^5$	0,080	0,530
10^5	0,400	2,590

The described methods for improving the accuracy of measuring sensor resistance are realized, in particular, in the inventions [6-8].

Conclusions

1 The errors were studied, which occur when quasi-invariance decreased IRW, while minimizing the ARL, as also the combination of ARL, IRW and SEF. Furthermore, it is revealed that when the coordinate of the location of the leak is equal to 0,5, an additional error occurs as an outcome of decrease in non-invariance IRW, with more than an order of magnitude greater than the maximum error of methodical transformation. The corresponding analytical expressions and graphs illustrate numerical examples.

2 The values of additional errors can be estimated by reducing IRW under the condition of invariance of ARL and SEF. Thus, the ways are identified to improve the precision of the depth parameters measurement transformed into the resistance of sensors.

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ИССЛЕДОВАНИЕ ПОГРЕШНОСТЕЙ ПРЕОБРАЗОВАНИЯ СОПРОТИВЛЕНИЯ РЕЗИСТИВНЫХ ДАТЧИКОВ ПРИ ОБЕСПЕЧЕНИИ КВАЗИИНВАРИАНТНОСТИ К СОПРОТИВЛЕНИЮ ИЗОЛЯЦИИ ПРОВОДОВ ЛИНИИ СВЯЗИ

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Аннотация. В предлагаемой статье рассматривается исследование погрешностей преобразования сопротивления резистивных датчиков при обеспечении квазиинвариантности к сопротивлению изоляции проводов линии связи в малопроводных измерительных системах (ИС). Разомкнутая структура (РС) преобразователя сопротивления резистивных датчиков (ПСРД) позволяет обеспечить инвариантность к изменению параметров канала связи (КС). Это гарантирует проведение работ в тяжёлых условиях, например, при глубинных измерениях в условиях высоких стационарных температур.

Ключевые слова: измерительная система, канал связи, разомкнутая структура, преобразование сопротивления резистивных датчиков, квазиинвариантность.

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