METHOD FOR ENSURING TEMPERATURE AND TIME STABILITY OF PARAMETERS OF MOLECULAR ELECTRONIC GEOPHYSICAL SENSORS FOR OIL AND GAS EXPLORATION SYSTEMS

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ABSTRACT

The paper presents a new technical solution for the device of the primary sensing element of the MET sensor that stabilizes the temperature characteristics of the device due to the fact that the background current flowing through the cathodes of the converting element is controlled by a specially designed electronic circuit depending on the ambient temperature. In this case, a current is passed through the anodes, the value of which depends on the temperature according to a certain law. The cathode current value is maintained when the temperature changes by changing the carrier concentration at the anode and the corresponding concentration gradient. Thus, the proposed mechanism stops the change in the diffusion coefficient with temperature due to the corresponding reverse change in the concentration gradient of the electrolyte carriers. The paper presents the theoretical basis of the proposed model and the experimental verification of the stabilization effect for the prototypes. Limit currents, voltage characteristics and a family of amplitude-frequency characteristics depending on the ambient temperature were measured. The stabilization effect is compared with the traditional scheme of sensitive elements.

Keywords: Sensor, geophone, accelerometer, temperature, sensitivity, molecular electronics, temperature stability

INTRODUCTION

The development of geophysics and seismic exploration requires active development of the new equipment that meets high requirements for accuracy, sensitivity, resolution etc. One of the most effective technologies for manufacturing linear motion sensors is the technology of molecular electron transfer (MET) [1,2]. The scope of MET sensors application of such sensors is extremely wide: geophysics, mining, seismic exploration and others [3,4]. At the same time, the specifics of using liquid electrolyte impose a number of physical restrictions on the use of MET sensors. First of all, the diffusion coefficient and viscosity of the liquid depend on temperature. That requires the development of the engineering solutions for efficient operation at different temperatures. Despite the absence of moving parts and suspensions in MET accelerometers and geophones, the active life of these devices is 10-15 years due to the degradation of the electrolyte composition. In this article, a new technical solution is proposed that allows reducing the temperature sensitivity of the amplitude-frequency response of the sensing element, and extending the active operation time of the device.

The most common design of a molecular-electronic transducer of mechanical motion to an electrical signal includes four electrodes placed in a closed circuit filled with an electrolyte, with the internal electrodes serving as cathodes, while the peripheral ones serve as anodes [5].

When connecting the electrodes of the molecular-electronic transducer to the electronics, the anodes are at a potential 250-300 mV higher than the cathodes. In this case, the concentration of the active component (tri-iodide ions) in the resting liquid on the anodes is approximately equal to the volume value, and on the cathodes it is close to zero [6, 7].

Background cathode currents in this case are determined by the supply rate of the reacting active component to the electrodes. In a stationary liquid, the transfer of active carriers is carried out by a diffusion mechanism, so the background cathode currents depend on the concentration gradient of the active component in the regions between the anodes and the cathodes, as well as the diffusion coefficient of active carriers, according to the expression:

$$I = -D \cdot S \cdot \left.\frac{\partial c}{\partial x}\right|_{x=x0_c} \tag{1}$$

Here D is the diffusion coefficient, S is the area of the corresponding cathode, and $\partial c/\partial x|_{x=x0_c}$ is the concentration gradient of the active component on the surface of the corresponding cathode (near-cathode concentration gradient).

In the presence of external mechanical disturbances, the liquid flows through the molecular-electronic transducer, and in addition to the diffusion one, the convective carrier transfer acts, increasing or decreasing the cathode currents, depending on the direction of the hydrodynamic flow. The coefficient of conversion of a mechanical signal to an electric cathode current in a molecular-electronic transducer is known to depend on the speed of the hydrodynamic flow, the gradient of the concentration of active ions in the cathode space, and the diffusion coefficient of the active ions [8, 9].

The parameters of the molecular-electronic transducer change with temperature, which is caused by temperature changes in the viscosity of the liquid and the diffusion coefficient. As the temperature drops, the viscosity increases. Accordingly, the flow rate of the liquid decreases with a fixed impact. At the same time, the diffusion coefficient decreases. Accordingly, the size of the region in the volume of the electrolyte, from which the carriers have time to reach the electrodes during the change in the mechanical signal, decreases. Both effects cause the conversion coefficient to drop as the temperature decreases. In particular, in the range from -40°C to + 65°, the drop can be up to several hundred times [2, 10, 11].

To reduce the temperature error of the transducer, a method which involves connecting the specified transducer to the electronics containing correction circuits with thermoresistors [12] can be used. When the ambient temperature changes, changing the resistance of the thermistor corrects the conversion factor. The main drawback of using correction circuits is that it is quite difficult to parry the drop in the transfer coefficient when the temperature changes over the entire operating frequency range. This requires more complex electronics and an increase in the number of components used in the accompanying electronics, which increases the noise of the measuring path [13].

The background current flowing through the cathodes of the transducing element is controlled by a specially designed electronic circuit depending on the ambient temperature. For this, the working fluid of the transducer at a distance from 2 to 50 mm from the anodes installed additional electrodes under potential 100-500 mV above the potential of the cathode. Between additional electrode and the anode current is passed, the value of which depends on the temperature according to a certain law. The action of the current passing through the anodes consists of a temperature-controlled change in the anode concentration, which increases with increasing current and decreases in the opposite case.

In turn, the value of the anode concentration determines the concentration gradient near the cathodes, and, consequently, the conversion coefficient. In this case, the temperature dependence of the current passed through the cathodes is selected so that the change in the concentration gradient in the cathode region compensates for the temperature changes in sensitivity in the region of high frequencies, which is more than 50 Hertz, due to the changes in the diffusion coefficient and the viscosity in the working fluid. Additionally, the temperature changes in the frequency range of less than 50 Hz are stabilized using a feedback mechanism.

THE DESIGN OF A NEW TYPE OF TRANSFER ELEMENT FOR THE TEMPERATURE STABILIZATION

The main objective of a new type of the MET cell is stabilization of the primary output parameters of the sensitive element during the temperature change. That could be achieved by changing the concentration of the active charge carriers in the anode region and, as a consequence, changing the concentration gradient of active charge carriers near the cathode.

The solution for the distribution of the concentration of the active component is sought in the form of expansion in powers of the fluid velocity. Therefore, the background current varies with temperature as a diffusion coefficient. The signal component of the current, which depends on the convective transfer of the active component, is related to temperature through the viscosity coefficient. Both factors lead to a decrease in the conversion coefficient with decreasing temperature [14, 15].

For temperature stabilization in a new type of cell, six symmetrically located electrodes are used. The design of this sensor and its connection to the electronics when the fluid is stationary are shown in Figure 1. In this case, the concentration of the active component at the cathode's «c» is close to zero. The output current generated on them is converted to voltage and amplified by operational amplifiers «OA», which are included in a differential circuit. The auxiliary electrodes «a el», which are located much further than the cathodes, are supplied with an electric potential «U0» of 100-500 mV above the potential of the cathodes. Accordingly, on the anodes that are connected to a constant current source «J», the potential is automatically set to ensure the flow of a mounted current. As a result, depending on the value of the source current, the concentration distribution is established. They are shown by the curves 1 and 2 in Figure 1. In the first case, the background current surpasses the background current when a usual four-electrode cell is connected. In the second case, the background current is less than the corresponding current when a four-electrode cell is connected. Due to the difference in the distance from the anode to the cathode and the auxiliary electrode, the main part of the current (> 90%) of the source goes to the cathodes. This ensures the constancy of the background cathode current. This means that with a change in temperature and a corresponding change of the diffusion coefficient in the expression (1), the concentration of the active component distribution should change so that the concentration gradient of the active component in the cathode region increases proportionally.

As a result, when the temperature changes, the following multidirectional factors will influence the behavior of the conversion coefficient. On the one hand, an increase in viscosity and a decrease in the diffusion coefficient should lead to a decrease in the conversion coefficient at lower temperatures. On the other hand, an increase in the near-cathode concentration gradient of the active component is to promote its growth.

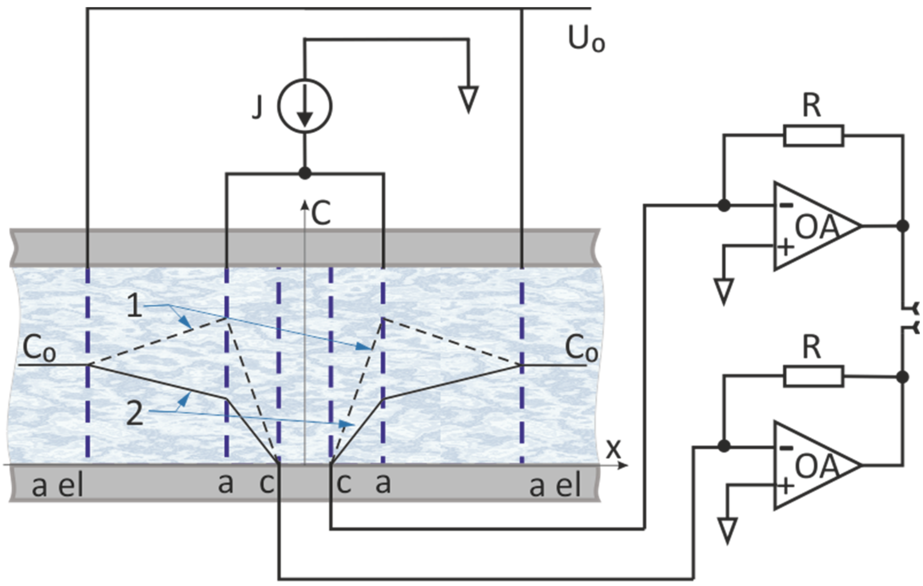

Figure 1 The design of the new sensitive element.

In general, the temperature dependence of the conversion coefficient is 3-4 times weaker than a traditional use of four electrodes cell. Thus, the requirements for a secondary electronic correction of the temperature dependencies are sharply reduced, the accuracy of the thermal compensation is increased and the noise of the measuring path is reduced.

THE EXPERIMENTAL STUDIES OF A NEW TYPE OF MET CELL

The following installation scheme was used to study the temperature dependencies, Figure 2.

The new modification of linear displacement MET sensors were placed vertically in a thermal chamber. The temperature conditions were created by the M-60/100-120 KTX thermal chamber. For the purity of the experiments, the electrical circuits were brought out.

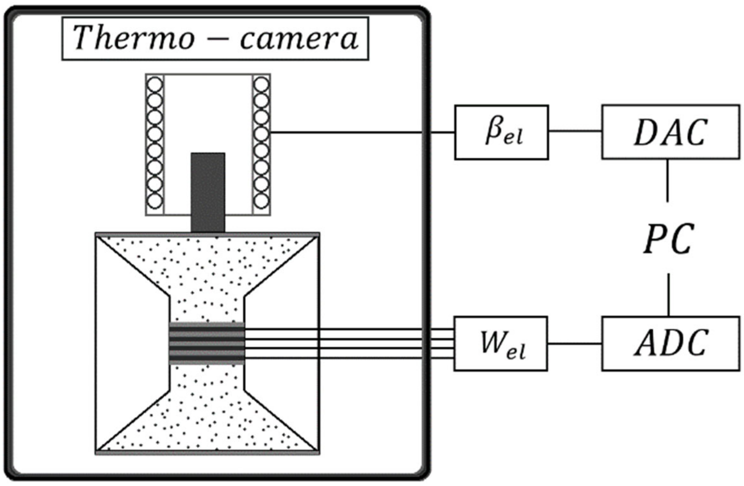

Figure 2. The installation diagram to study the temperature dependence of the MET devices.

The National Instruments NI-6215 data collection system was used to obtain the amplitude-frequency characteristics of an open-loop device. Calibration was performed as follows. The specified signal was fed through the DAC to an electromagnetic coil in the feedback loop. The force created by the action of the coil field on the magnetic core created the acceleration of the liquid in the electrode node. Changing the concentration gradient of the ions created the current on the MET electrodes, which after passing through the electronics with a known transfer function was converted into a voltage signal. This signal, recorded using a data acquisition system, was fed to a PC.

Then, for each frequency, the signal spectrum from the sensor was constructed. The maximum of this spectrum was divided by the same maximum of the signal from the generator. From the points obtained in this way, the frequency response of the devices in units of applied acceleration was obtained. The instruments were calibrated using sinusoidal signals in the range from 0.5 to 660 Hz at various temperatures.

The dependence of the background current values on temperature was also removed. To do this, the voltage drops were measured on resistors R in the signal conversion stage from current to voltage (Figure 3).

Families of transfer functions for the devices of a new type with steps every 15 °C were obtained. Additionally, the dependences of the background currents on temperature for the same linear displacement sensors are obtained. The experimental data are presented in Figure 4 and Figure 5.

In this work, sensors filled with electrolyte were studied: an aqueous solution of LI (4 mol/l, with the addition of I_2 0.1 mol/l), electrode nodes of 3x3 mm in size, the distance to the additional electrode was about 10 mm, the area of the additional electrodes was 8 mm^2 of each electrode.

The experimental studies of a limitation currents of a new MET cell were performed. The results are presented in the Table 1 where the current which the cell is able to pass without losing the signal conversion quality can be found.

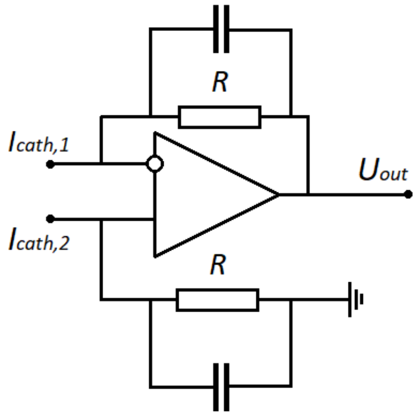

Figure 3. Circuit of the current-to-voltage converter stage.

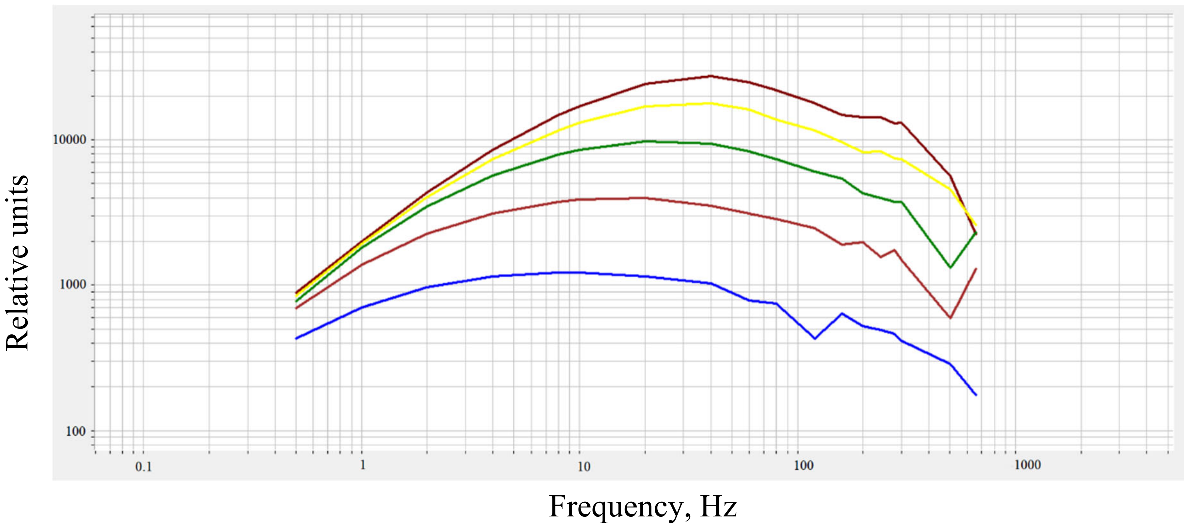

Figure 4. The family of the transfer functions for a device with additional grid-shaped electrodes (in the range from +40°C to -20 °C in increments of 15°C)

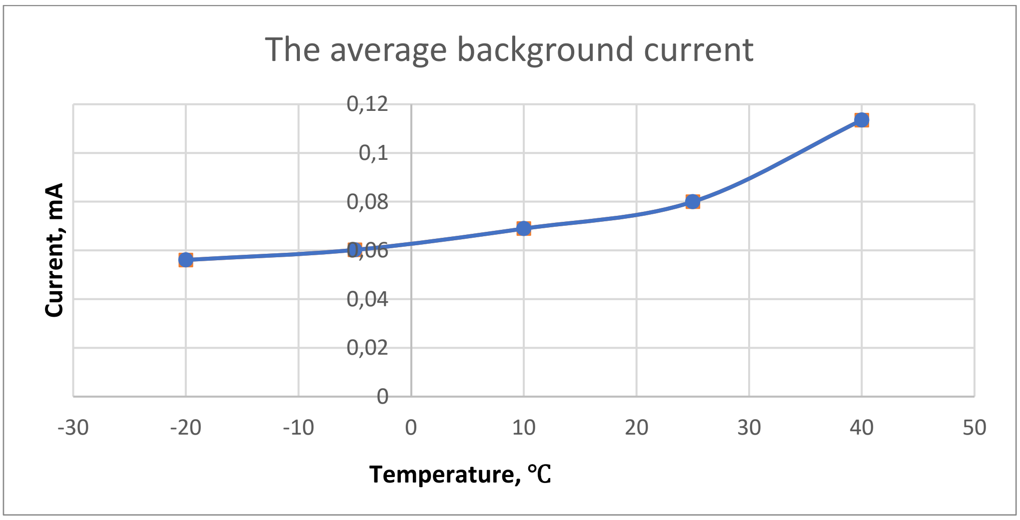

Figure 5. Dependencies of the average background current on the temperature for the new cell type

Table 1. Limit currents for an additional 2x2 mm additional electrode at 25°C

R, kOm	U_{ak}, B	U_R, B	U_{300}, B	U_{k1}, B	U_{k2}, B	U_{ade}, мB
71	0,302	6,68	0,309	0,72	0,52	7
62	0,304	6,62	0,309	0,78	0,55	3,5
56	0,303	6,56	0,31	0,83	0,59	2,5
51	0,304	6,54	0,31	0,85	0,614	1,7
43	0,306	6,21	0,308	1,02	0,72	1,1
20	0,317	5,83	0,309	1,59	1,12	7
10	0,329	5,19	0,309	2,26	1,65	18
5,1	0,332	3,63	0,309	3,74	2,65	23
3	0,347	2,69	0,309	4,7	3,31	33
1	0,362	1,26	0,309	6,08	4,28	38

Where U_{ak} is the voltage between the anode and the cathode, R is the resistor that sets the current generator to the anodes, U_r is a drop of the resistor that sets the current generator to the anodes, U_{300} is the voltage on the board between the legs of the cathode and additional electrode, U_{ade} is the voltage between the anode and the additional electrode, U_{k1} and U_{k2} are the voltages on the 1st and 2nd shoulders, respectively.

This table shows that it is possible to vary the input current in a region of 4-5 times from the feedback current of a traditional scheme of the MET cell. That seems to be sufficient for the temperature feedback current variations.

CONCLUSION

The proposed technical solution for a new type of the electrode assembly for linear motion sensors (accelerometers and geophones) for oil and gas exploration can significantly reduce the temperature dependence of the traditional sensing elements. Preliminary experiments have shown proper performance of the proposed technical solution. The temperature dependence of the new type of node for the first experimental samples was several times lower than the traditional schemes. At the same time, the studied limiting currents demonstrate the necessary current margin to compensate for the decrease in the diffusion coefficient. Further research involves studying the dependence of the technical characteristics of transducers of the area of additional electrodes, their distance to the anodes, the type of circuit for the current generator, noise and dynamic characteristics of the device as a whole.

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