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Signal Simulation Electric Systems of Admittance Monitoring

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Abstract: Admittance method is proposed to evolve the mathematical model of electric systems of monitoring the nonelectric nature object quality. The analysis of response models for water salt-solutions due the results of admittance monitoring has been conducted, to detect the peculiar properties of response surfaces. The possibility of applying the models of reactive conductivity component dependence on salt solution concentration and frequency of a test signal is suggested for maintaining and calibrating a measuring device.

Keywords: Leave mathematical model, Admittance monitoring, Nonelectric nature objects, Salt solution, Capacitance sensor, Reactive conductivity component.

1. Introduction

The research of the system “primary transducer – control object” (PT – CO) in the real scale is a highly laborious task. Its complexity is caused by a number of influence-factors, and considerable interlacing of their mutual connections as well as those with system elements. One of the ways of those systems’ study is a design of a mathematical model that should include the immanent characteristics of a real system. The investigation of a mathematical model in its turn allows us to sift the essential characteristics of the researched system [1-3].

The systems of monitoring the nonelectric nature objects’ quality by dint of the admittance method constitute a subject of the proposed mathematical simulation. The admittance method is grounded on measuring the active G and reactive B components of complex conductivity [4]. It is worth noting that till recent time the admittance method was involved in the research of electric nature objects only, namely the elements of electric circuits: resistors, condensers, induction coils and etc. However the objects of nonelectric nature are much more frequent in our environment, e. g., water, soils, food products, wares of light industry and so on. Those objects are rather nontraditional for admittance monitoring [5-7].

Thus the necessity of studying the peculiarities of admittance method application in the estimation of quality indices of nonelectric nature objects is of topicality nowadays. For this purpose we should substantiate the choice of immanent parameters of the system “primary transducer – control object”. According to the experimental values of these peculiar parameters, the mathematical model covering also the effects of controlled medium parameters on the nature of PT-CO system responses at the simultaneous alteration of those parameters

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should be evolved. The objectives of the proposed work include the study into the peculiarities of the admittance monitoring method applied to the objects of nonelectric nature, namely water salt-solutions.

2. Results of Investigations

2.1. Equipment and Conditions of Research

The experiments were carried out with the usage of an immittance-meter with a primary transducer of capacitance type. The range of the researched frequencies made: 25 Hz - 1 MHz, voltage level of a test signal: 0.01 V - 2 V, electrode material: platinum, distance between electrodes: 5 mm, and length of a transducer working part: 6 mm. The stability of electrodes was assured by their soldering into the chemically stable glass tubes.

2.2. Analysis of the Researched System Parameters

The admittance method of object research is based on measuring and stiffing the dependence of admittance on the frequency *F* [8, 9]. Different objects and processes are characterized by different frequency dependences of active and reactive admittance components, which allows us to solve the reverse problem, i.e. to extract information on those objects by dint of analyzing their response frequency characteristics in the form of the reactive admittance component *B*. Thus the immittance method whose informative parameter in a concrete case is admittance enables assessing the quality of nonelectric nature objects through their electric parameters. Hereby, the chemical properties of nonelectric nature objects could be represented in the form of the electric models described by mathematical expressions.

The structure of the researched system is notified in the Fig. 1.

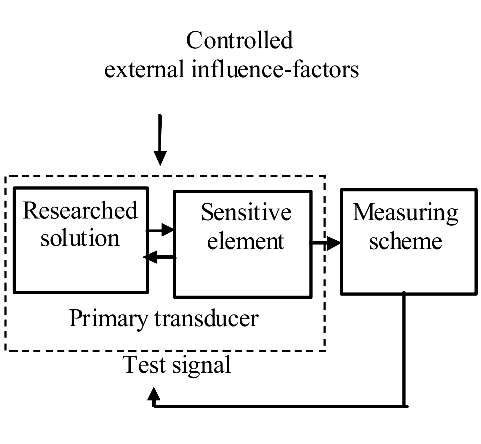


Fig. 1. Structure of the researched system Immittance PT-CO.

The peculiar parameter of the researched object, water salt-solution, is the index of its chemical composition – the salt concentration in the solution *C*. Since the object of our research is water solution, i.e. the conductor of the second type, one of the external factors of influence on the PT-CO system is the temperature *T*, whose influence nature requires further specification.

The application of the admittance method consists in the usage of some test signal of the voltage *U*, whose responses are under consideration. The parameters of a capacitance primary transducer could be represented by its geometric sizes, namely by the constant *K* that is determined by the ratio of a distance between electrodes *L* to the area of those electrodes *S*.

Thus the set of PT-CO system parameters for water salt-solution includes the concentration of salt-solution *C*, voltage value of test signals *U*, their frequency *F*, solution temperature *T* and also the mentioned before constant *K*.

2.3. Development and Analysis of Mathematical Model of a Signal in the Researched System

According to the expounded before analysis, the research on water salt-solutions with the usage of the admittance method is characterized by such parameters:
- Concentration of salt-solution *C*;
- Value of test signals' voltage *U*;
- Frequency of test signals *F*;
- Solution temperature *T*;
- Constant *K* characterizing the geometric sizes of electrodes.

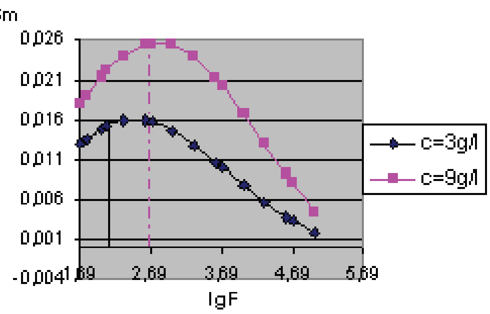
It means that the response signal *Y* could be described by some function:

$$Y = f(C, U, F, T, K) \quad (1)$$

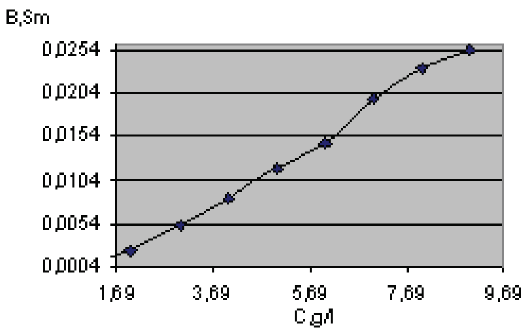
In general case the dependence (1) is quite complicated. To simplify it, we should investigate the dependence of the response signal *Y* on the less number of parameters at the certain fixed values of others [10-13]. This approach enables undertaking the separate research on the dependences of a response signal on certain parameters, and graphically visualizes their results.

The conducted experimental research has proved that the alteration in a response signal does not depend considerably on the change in test voltage values *U*. Apart from, the research is normally being conducted using the same primary transducer, to wit, the size-dependent constant *K* does not change within the experiment. Thus while applying the admittance method in the research on water salt-solution we could restrict the number of influence-parameters to three: salt-solution concentration, test signal frequency and temperature.

The experimental research has been carried out for different value combinations of the indicated parameters particularly the concentration has been changed within the range from 1 g/l to 9 g/l, frequency – from 0.05 kHz to 100 kHz, and temperature – from 20 °C to 50 °C. The additional analysis of the dependence of a response signal at the fixed values of salt-solution concentration and temperature has also been performed. The premise of this analysis was made by the research in the dependences of system responses on one changing parameter, under the condition of steadiness of others. Particularly the Fig. 2 (a) represents the dependence of a reactive conductivity component on the frequency of a test signal for various fixed values of salt-solution concentration. The dependence of a reactive conductivity component on the concentration of salt-solution at the fixed value of test signal frequency (F = 1 kHz) is notified in the Fig. 2 (b). The value of test signal frequency was logarithmized (lg$F$) for the convenience of experiment result processing.



(a)



(b)

Fig. 2. The dependences of a reactive conductivity component at (a) the fixed values of salt-solution concentration; (b) the fixed value of test signal frequency.

According to the results of the experiments conducted at the fixed temperature value, the dependence of a response signal on the concentration of NaCl solution and frequency of a test signal has been derived:

$$B = f_T(C, F), \qquad (2)$$

where B is the reactive conductivity component.

To describe this dependence after the method of the smallest squares, the following expression has been got:

$$\begin{aligned}\hat{B}(\lg F, C) &= 0.00868 - 0{,}0091 \cdot \lg F - \\ &- 0{,}0054 \cdot C + 0{,}0075 \cdot \lg F \cdot C + \\ &+ 0{,}00261 \cdot (\lg F)^2 + 0{,}00022 \cdot (\lg F)^3 \cdot C - \\ &- 0{,}00243 \cdot (\lg F)^2 \cdot C + 0{,}00008 \cdot (\lg F) \cdot C^2 - \\ &- 0{,}00022 \cdot (\lg F)^3 - 0{,}0000027 \cdot (\lg F)^3 \cdot C^2.\end{aligned} \qquad (3)$$

The expression (3) was calculated on the basis of 144 experimental values, gained for 9 different values of salt-solution concentration and 15 different values of test signal frequency. The observed values of a reactive conductivity component were changed from 0.0000703 Sm to 0.0256358 Sm. Since the values of reactive conductivity could change almost 1000 times as much, the method of the smallest squares with a relative error was applied to the derivation of the expression (3). The average relative error of reactive conductivity component reproducing by the model (3) makes 8 %, and the determination coefficient makes R^2 = 0.9. The largest value of a relative error, near 30 %, was fixed only in one point that corresponds to the maximal concentration of salt-solution 9 g/l and minimal signal frequency 0.05 kHz, and the relative error of more than 13 % was observed in four points.

The research on the mathematical model (3) has made it possible to characterize the system peculiarities in the different sub bandwidths of signal frequency and temperature alteration. So at the frequency alteration within the range of values due to which the model (3) was built, a response surface acquires a characteristic sag, whose maximum tends to shift with the rise in frequency and salt-solution concentration C (Fig. 2 (a), Fig. 3 (a)). The dependence of a reactive conductivity component at the fixed values of salt-solution concentration is notified in the Fig. 3 (b), Fig. 4 (a), Fig. 3 (d) and Fig. 4 (c). The system response surface for frequencies F, exceeding the bandwidth that serves as a basis for the model 3, thus constituting the predictable values of a response surface, is represented in the Fig. 3 (d), Fig. 4 (c).

The possibility of applying the model (3) to the frequency values of test signals outside the underlying range of the model (3) has been proved experimentally. Particularly, the representations in the Fig. 3 (c), Fig. 4 (b) prove the possibility of applying the model (3) to the higher values of test signal frequencies. It is worth mentioning that in the case of predictable values of signal frequency alteration F within the bandwidth from 10 kHz to 1000 kHz (look Fig. 4 (c)), a response surface also has a typical sag – minimal values of response signal are displacing with the rise in signal frequency and salt-solution concentration C which also was confirmed by the results of observation (Fig. 4 (b)).

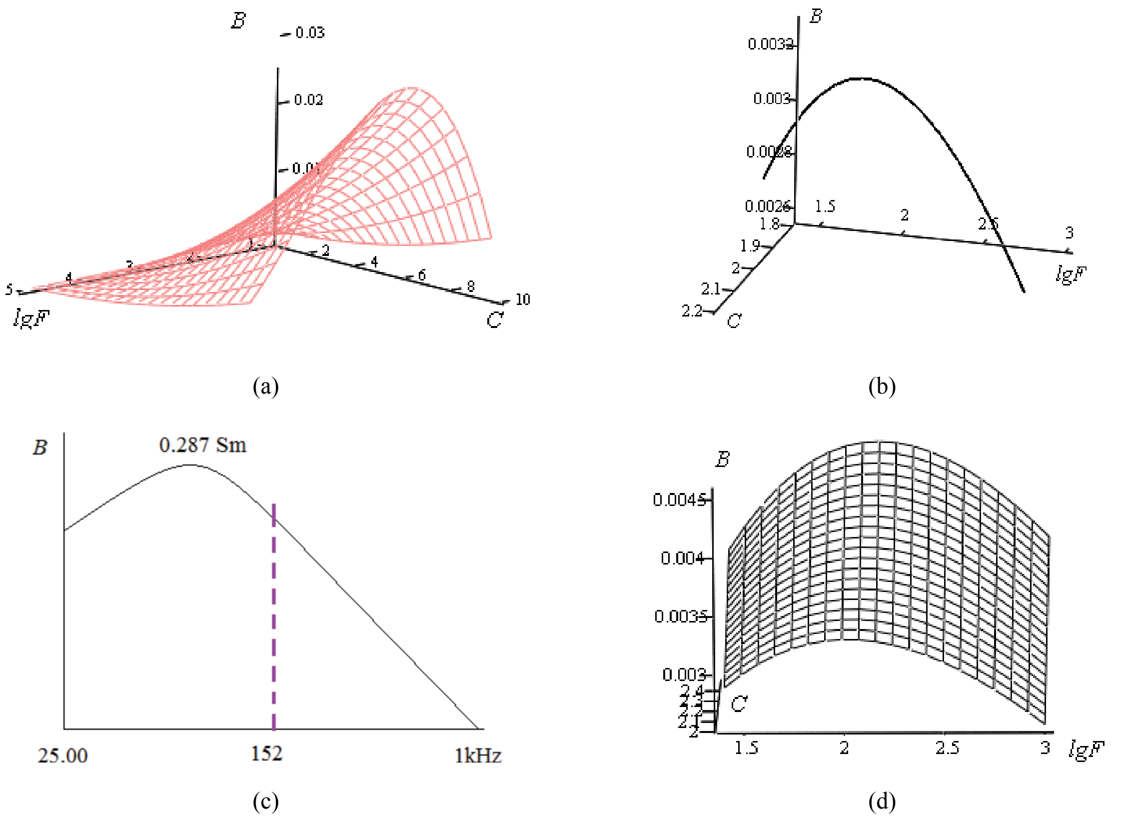


Fig. 3. The reflection of a system response surface: (a) within the range of parameters supporting the mathematical model (3); (b) and (c) at the fixed solution concentration C=1 g/l and within the bandwidth F = (0.025÷1) kHz (constructed according to an experiment model); (d) within the range C = (1÷3) g/l, F = (0.025÷1) kHz, constructed on a basis of the model.

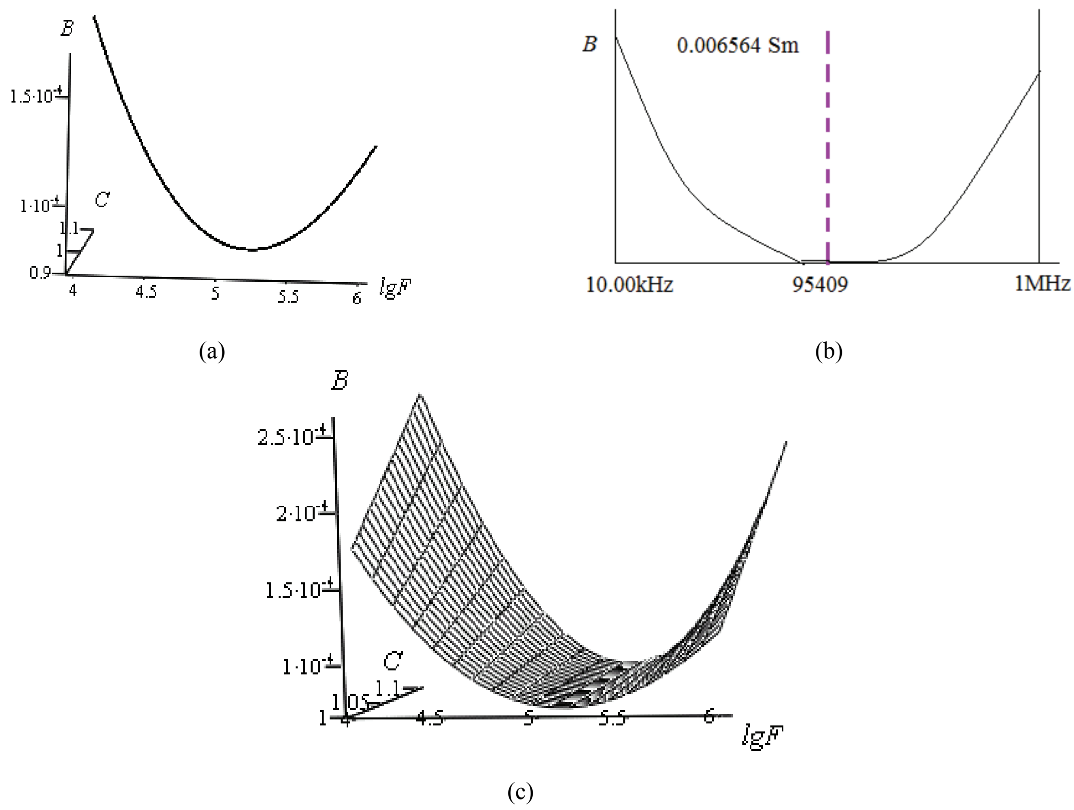


Fig. 4. The reflection of a system response surface: (a), (b) at the fixed solution concentration C = 1g/l and within the bandwidth F = (10÷1000) kHz, correspondently constructed on a basis of the model and experiment; (c) within the range C = (1÷3) g/l, F = (10÷1000) kHz, constructed on a basis of the model.

To wit, following the results of model analysis (3), we could observe the characteristic sags of a system response surface. The maximal values of reactive conductivity, reached while increasing the test signal frequency, are fixed at the largest solution concentrations.

At the fixed values of salt-solution concentration, the dependence of system responses on signal frequency and solution temperature has been researched:

$$B = f_C(F,T) \quad (4)$$

In accordance with the results of observing the dependence of reactive conductivity component of NaCl water solution on signal frequency and solution temperature, the following expression has been derived:

$$\begin{aligned}\hat{B}(\lg F,T) = &-0{,}01223 + 0{,}015574 \cdot \lg F + \\ &+ 0{,}00007303 \cdot T - 0{,}000027 \cdot \lg F \cdot T - \\ &- 0{,}006158 \cdot (\lg F)^2 + 0{,}0000026 \cdot (\lg F)^2 \cdot T + \\ &+ 0{,}0008492 \cdot (\lg F)^3 - 0{,}0000057 \cdot (\lg F)^5.\end{aligned} \quad (5)$$

The expression (5) has been calculated after the method of the smallest squares with an appropriate relative error on the ground of 80 observations through a reactive system conductivity component for the signal frequency within the bandwidth from 0.05 kHz to 100 kHz and solution temperature - from 33 °C to 50 °C. Since the observed values of a reactive system conductivity component have been altered within the range [0.0000372 Sm; 0.002482 Sm], the model (5) has been calculated under the condition of a minimum of relative error squares' sum. The average value of relative error of reactive conductivity component reproducing by the model (5) makes 0.03 %, and the determination coefficient makes $R^2 = 1.1$. The largest value of the relative error of the model (5), near 16 %, has been observed only in one point that corresponds to the temperature 33 °C and signal frequency 20 kHz; the considerably lower values of the relative error have pertained to other observation points.

The dependence of reactive system conductivity component on temperature at the fixed concentration of salt solution is practically linear (Fig. 5).

The research on the mathematical model (5) has enabled characterizing the system peculiarities for different alteration ranges of test signal frequency and temperature. So with altering the frequency within the range of model (5) underlying values, a response surface has acquired a typical sag – its maximum is not shifting with the rise in frequency and temperature at the given fixed solution concentration, but augmenting monotonously with temperature rise (Fig. 6 (a)).

The system responses within the range of temperature alteration values from 0 °C to 20 °C, exceeding the values of the model (5), are reflected in the Fig. 6 (b). The response surface representation in the Fig. 6 (b) shows that the nature of the dependence of a reactive NaCl solution conductivity component on signal frequency at the decrease in temperature is stable – a fall in the response value corresponds exactly with that of temperature.

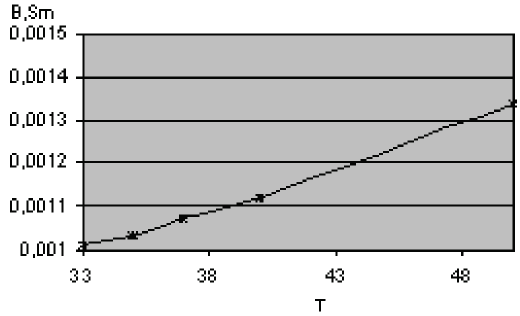
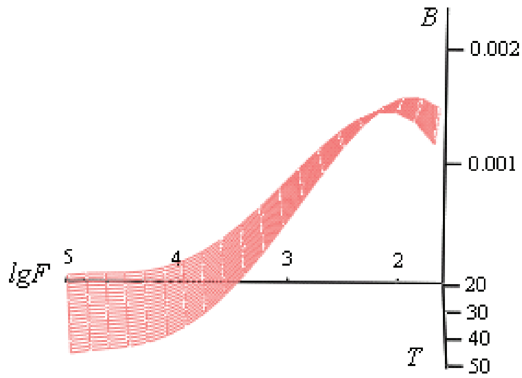
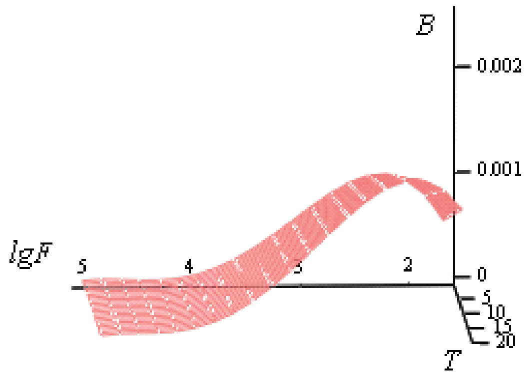


Fig. 5. Dependence of reactive system conductivity component on temperature at the fixed solution concentration.



(a)



(b)

Fig. 6. Dependence of probability of the revealed fluctuations on the time of disequilibrium system observation.

Thus according to the results of analyzing the models (3) and (5), we might observe the typical sags of a system response surface. The maximal values of reactive conductivity at the increase in test signal frequency are observed for higher solution concentrations. With the rise in solution temperature, those maximal values are increasing proportionally.

3. Conclusions

The conducted research supports the possibility of applying the admittance method to the assessment of nonelectric nature objects' quality. The gained models of the dependence of reactive response signal conductivity on the concentration of water salt-solution, its temperature and test signal frequency prove the expediency of involving them in the research into the nature of reactive conductivity dependence on these parameters.

Due to the analysis of these models the availability of reactive conductivity maximal values at the certain values of test signal frequency and salt-solution concentration has been revealed. With the rise in solution temperature those maximal values are increasing proportionally. This peculiarity of reactive conductivity dependence on solution concentration and test signal frequency could be employed during the maintaining and graduating of measuring devices.

Acknowledgements

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