Selection and justification of efficiency parameters of a noise-resistant downhole telemetry system

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Abstract. The article examines the issue of selecting and justifying efficiency parameters of a noise-resistant downhole telemetry system that measures and transmits borehole information to the surface via an electromagnetic communication channel. The work is devoted to the continuation of research on the synthesis of systems capable of transmitting messages from oil wells equipped with sucker rod pumps from a depth of up to two thousand meters. To ensure noise immunity, coding is proposed in the residual class system with the possibility of error correction in the neural network basis.

1. Introduction
One of the main tasks of increasing the degree of oil reserves recovery is the availability of reliable information about deposits [1–5]. When conducting hydrodynamic studies of oil and gas wells using submersible telemetry systems, one of the most important issues is the transmission of well information to the so-called “day surface” [6]. In this case, the transmission of information through an electromagnetic communication channel under the influence of various interference is particularly difficult. Interference is any disturbance in the information transmission channel that causes random deviations of the received message from the transmitted one and makes it difficult to receive it. Interference (or noise) immunity is understood as the ability of an information system to withstand the harmful effects of interference. As a result of interference, the received message will differ to some extent from the transmitted one. Therefore, noise immunity can be characterized as the degree of correspondence of the received message to the transmitted one for a given interference. When comparing several systems, the most noise-resistant will be the one that, with the same interference, will provide a smaller difference between the received and transmitted messages.

Telemetry information is data on temperature, pressure, flow rate, water content in the mixture, etc. To ensure the noise immunity of the communication channel, the research uses transmitters with increased power and supersensitive receivers. They reduce the range to low and ultra-low frequencies and duplicate broadband signal transmission. In order to detect, localize and correct computational errors during digital signal processing, the research uses modular number systems with this ability [7–9].

In its most general form, the solution to the problem of increasing noise immunity of telemetric information transmission encounters certain difficulties and, to obtain practical results, the problem can be divided into two subtasks:
1. Optimization of the “digital channel” subsystem, implying the choice of the best signal type, type of carrier, modulation method and the corresponding best reception method.

2. Optimization of the subsystem “encoder-decoder” of a digital channel.

The results obtained make it possible to effectively solve the problem of increasing the efficiency of the development of deposits with hard-to-recover backflows [10–12].

2. Materials and methods

General statement of the problem of synthesis of a noise resistant telemetric system

In [6], the conditions for solving the first subproblem are described in sufficient detail, which implies the selection and justification of devices for an electromagnetic channel, primary and secondary sealing, an autonomous power supply system, etc.

In this work, special attention is paid to the formulation of the second problem associated with increasing the noise immunity of information transmission.

The multilevel structure of the telemetric system and the complex functional interconnection of the individual elements of the system with each other make it necessary to classify it as a complex system. The quality of the system is usually characterized by a large set of indicators written in the form of a vector.

\[ E = (E_1, E_2, ..., E_n). \] (1)

The optimal system is considered to be the one to which the largest (smallest) value of some function

\[ E = \varphi(E_1, E_2, ..., E_n), \] (2)

from private quality indicators \( E_1, E_2, ..., E_n \), where \( E \) is the system efficiency, and \( \varphi(E_1, E_2, ..., E_n) \) is the target function of the system.

In the simplest cases, the efficiency of the system is assessed by the most essential parameters

\[ \varphi(E_1, E_2, ..., E_n) = E_0, \] (3)

where \( E_0 \) is the main quality indicator that needs to be maximized. Generally, a systematic approach is necessary, which assesses the efficiency of the system as a whole by a set of parameters. In this case, it is necessary to take into account the most essential parameters of the system being developed.

The desire to take into account all parameters leads to the complication of the assessment results. However, over-limiting the number of parameters may lead to the estimate being too rough. In this regard, it is fashionable to propose an estimate in the form of a linear function

\[ E = \sum_{i=1}^{m} \lambda_i \zeta_i, \] (4)

where \( m \) is the number of parameters taken into account. The relative values of the weight \( \lambda_i \) and the relative values of the parameters \( \zeta_i \) are determined as follows. Let the main parameters of the system be set by the values \( C_i(C_i > 0) \) by the upper and lower limits \( C_{i_{\text{max}}} \) and \( C_{i_{\text{min}}} \), respectively. Then the relative value of the parameter having the upper bound will be determined by the ratio:

\[ \lambda_i = \frac{C_i}{C_{i_{\text{max}}}}. \] (5)

and the relative value of the parameter having the lower bound is by the ratio:

\[ \lambda_i = \frac{C_i}{C_{i_{\text{min}}}}. \] (6)

Each parameter is characterized by some weight \( \rho_i \) or relative weight:

\[ \lambda_i = \frac{\rho_i}{\sum_{i=1}^{n} \rho_i}. \] (7)

With this definition of the parameters included in (4), it is obvious that \( 0 \leq E \leq 1 \). The best system is one for which \( E \) is larger. The choice of the weighting coefficients \( \rho_i \) is determined relatively arbitrarily, which equally applies to the number of parameters \( n \).

Evaluation of the effectiveness of a telemetry system with an electromagnetic communication channel by one indicator is attractive in that it is expressed by the same number and takes into account all the selected parameters of the system. However, modern systems cannot always be fully characterized by one indicator. The score for several indicators may be more specific. Evaluations of the telemetry system for several indicators are also justified by the fact that they are only the basis for analysis in order to make a decision. The final decision, as a rule, is based not only on quantitative
calculation data, but also on experience, intuition, as well as additional considerations that were not taken into account when constructing a mathematical model.

*Selection of the set of parameters for estimating the efficiency of an immunity telemetric system*

In order to ensure high noise immunity when transmitting telemetric information from the well to the day surface, the following characteristics can be selected:
- temporary;
- reliable;
- operational
- probabilistic.

From each subset it is necessary to select one defining parameter, which most characterizes its subset.

Such parameters that determine the quality of the system functioning include:
- the probability of non-detection of an error by the \( P_{ND} \), system, which is an assessment of the reliability of the transfer of information such as pressure, flow rate, water content in the mixture and temperature;
- noise immunity \( P_n \), defined as the probability of correct message reception in the form of a noise-like signal with modular coding;
- probability of loss (error detection) \( P_{ED} \) – probability of transformation of the transmitted message into an erasure signal;
- transmission rate \( R \), characterized by the ratio of the number of received messages in time \( t_i \) to time \( t \);
- time of delivery of messages \( T \).

In systems with a non-deterministic number of repetitions, the transmission time of each message depends on the specific conditions of passage through the communication channel and is a random variable. The average transmission time of one message for characteristics of system properties is determined during the research.

One of the urgent tasks of improving the system is also to reduce hardware costs. This problem can be solved not only on the basis of simplifying algorithms, processing, but also on the main reduction in memory. The complexity of the latter can be estimated using known indicators.

3. Conclusion

The considered first set of aspects is essential for choosing a set of parameters. Parameters \( P_{ND}, P_n, R \) and \( T \) are usually determined on the assumption of using absolutely reliable equipment operating in conditions of real interference caused by the natural background of the earth, interference from nearby high-power power cables, etc. Therefore, the parameter values calculated under these conditions determine the quality transmission algorithms and methods for protecting information from errors.

Some of the listed characteristics will be used to assess the increase in noise immunity of information transmission in the telemetry system of wells equipped with sucker rod pumps, which ultimately will improve the reliability of receiving telemetry information transmitted via the electromagnetic communication channel, and thus, qualitatively conduct hydrodynamic studies of an oil well.

The need to transfer protective coding to a neural network basis should be noted as a second set of aspects [6]. The most attractive in this regard are systems based on neural networks using coding by means of modular information representation. This aspect is becoming especially relevant in the period of the emergence of a relatively new organization of ultra-high-speed computing - neural networks.

Neural networks (NN) begin to play an increasingly important and noticeable role at all stages of the life cycle of computing process control in digital signal processing. Currently, there are three main scientific directions in the field of neuromathematics:
- theory of neural networks;
• neuroinformatics (using the theory of neural networks to develop algorithms for solving problems);
• neurons and neurocomputers.

Now there is every reason to believe that any tasks in the field of digital signal processing should be more efficiently solved on neurocomputers, since the algorithm of any task can be represented in a logical basis with a controlled number of layers of neurons. This means that the neural network algorithm for solving any problem at the logical level is more parallel than any conceivable physical implementation of it. Consequently, the potential for high-speed information processing is initially incorporated in NN.

The special value of neural networks, in relation to the issues of ensuring high noise immunity, lies in the fact that they are self-organizing. This means that the system is capable of learning, and, consequently, of independent detection and correction of errors that arise within it.

At the same time, the creation of this theory gave rise to many questions related to its implementation. As it turned out, the models of modern artificial neural networks are for the most part a purely mathematical interpretation of the construction of biological neural networks, which leads to the loss of a significant part of the capabilities of their biological prototype.

In this regard, the most appropriate is the use of modular number systems, and in particular, the system of residues.

The experience of designing the first computing devices based on modular information coding has shown that, in terms of increasing the speed and reliability of processing numerical information, residue systems have more capabilities than conventional positional number systems. As is known, the noise immunity of processors is ensured by introducing various forms of redundancy: hardware, software and time redundancy. From the point of view of providing hardware redundancy, one can use a special coding that has not only parallelism properties, but also natural correcting capabilities. Studies have shown that in the numbers theory, there is a modular number system in residues based on the Chinese Sun Tzu remainder theorem. This non-positional modular system not only allows parallelizing the execution of machine operations, but also has the ability to provide information redundancy. The uniqueness of the residue system lies in the fact that the information processing hardware in this system is easily controlled and diagnosed. This is due to the specific features of the representation and processing of code structures in the system of residues and the manifestation of failures in them [9].

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