# Development of software and hardware models of monitoring, control, and data transfer to improve safety of downhole motor during drilling

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**Abstract.** The article is concerned with the problem of transmitting data from telemetric devices in order to provide automated systems for the electric drive control of oil-extracting equipment. The paper given discusses the possibility to use a logging cable as means of signal transfer. Simulation models of signaling and relay-contact circuits for monitoring critical drive parameters are under discussion. The authors suggest applying the operator $\oplus$ (excluding OR) to increase anti-jamming effects and to get a more reliable noise filter.

## 1.  Introduction

The problem of efficiency and safety of oil production is acute all over the world [1,2]. Oil production is a complex technological process. To transmit the readings from the telemetry system, that is, in the well, both cable and wireless data transmission channels are used, in which, with a high probability, the transmitted data are subject to interference [3]. To implement the mathematical support for monitoring and management when drilling a well, it is necessary to develop tools for analyzing the states of the drill drive [4].

## 2.  Equipment and devices used in studies

In the research, the authors used controller OMRON. The operator's panel is connected to controller OMRON [5]. In this paper, the data transfer model studies were carried out using the SimPowerSystems package (MATLAB \ Simulink), and the studies on monitoring and control of the electric drill with the OMRON CX-Programmer version 7.1 and CX-Designer software.

## 3.  Results and discussion

The object under study is transmitted information, which is represented by pressure, acceleration of the vibration of the electric drill rotor, formation temperature, current strength, power consumption and other parameters. When a wired channel is used, a high level of electromagnetic interference occurs. The use of submersible telemetry systems will significantly increase the service life of the equipment.

There is a need to improve data transmission in downhole telemetry systems. Approaches are known for data transfer using a wireline cable. To improve the recognition of transmitted data, a phase modulation of the Barker sequence was proposed [6]. The disadvantages of these approaches were the complexity of the processing algorithm and the large amount of overhead information [7].

The purpose of this work was to study the data transmission model for a wireline cable and to conduct parametric signal modulation studies (carrier / noise length) to ensure safe operation of oil wells. At the preliminary stage of the simulation, the telemetry system (TMS) used in the fields is considered, and the operation of the main nodes that are directly involved in data transmission using a wireline cable is described. The structure of TMS includes the following elements: the power electric system, the control unit, the submersible telemetry unit, OMRON firmware.

Through the ground transformer, electrical energy is transferred to the pump. The junction point in the star is connected to the ground telemetry unit, and the phase ends are connected to the armored wireline cable, which is lowered directly into the well, feeding a high voltage to the oil electric pump (NEN). Measuring information, including monitoring and control on the part of downhole instruments, is also proposed to be transmitted over a wireline cable. The logging cable is a cable with a sufficiently large (up to several tons) breaking force, which carries wells in chemically and mechanically aggressive well environment [8,9].

Changes in the potential at the junction point of the windings lead to a change in the zero point of the three-phase transformer, which allows the ground unit to register changes and thereby to obtain a code combination that can be used to generate digital data. The submersible telemetry block consists of 2 blocks: the processor unit and the interface unit. The functions of the immersion unit are: measuring the temperature of the motor windings, measuring the ambient pressure, measuring the vibration along the $X$ and $Y$ axes and measuring the temperature inside the device. As a processor unit, it is proposed to use the OMRON microcontroller [10,11].

The programming language of the OMRON CP1L controller was relay-contact logic (IEC61131-3). The monitoring of the current valuesof the measured parameters and the boundary maximum value was recorded in the data memory cells. As parameters of monitoring, the temperature of the motor windings, rock pressure, vibration, current intensity, thermal (moisture) protection of the pump acted. The electric drill operator's panel was designed using the CX-Designer.When the permissible values are exceeded, a red indicator lights up on the operator panel and the drill turns off automatically. Manual on / off of the drill occurs on the control panel using the buttons of the trigger type. The developed relay-contact scheme for controlling the electric drive of the drill is shown in Figure 1.



**Figure1**. The relay-contact diagram for monitoring and controlling the electric drive of the drill. Boom Drive Simulation

A fragment of the condition block for setting the permissible parameters is shown in Figure 2.

**Figure 2.** The fragment of the block of conditions for setting permissible parameter values

Figures 3 show a simulated emergency shutdown of the drill drive. In the development of the data transmission model, digital signal transmission using a carrier and a modulated signal was proposed. The variation of various modulations was studied with the purpose of fixing the signal change and determining the nature of the signal transmission through the logging cable. The model was the structure of the telemetry system. In it, there was a source of three-phase voltage, in reality it acts as a three-phase transformer supplying an electric drill. Then the sequence from RLC simulates a cable having active and reactive resistances $R$, inductance $L$ and capacitance $C$.
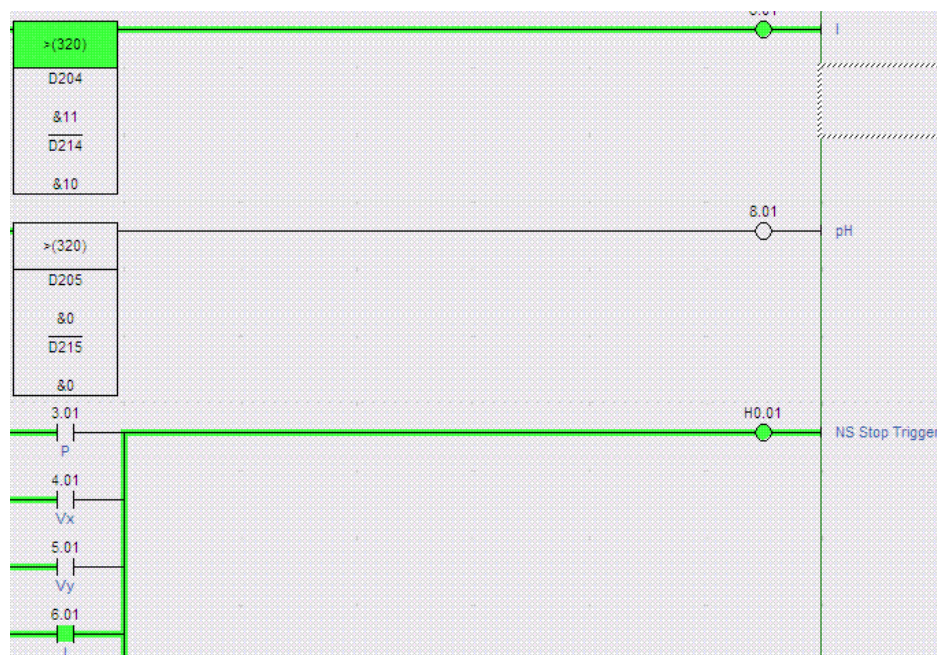


**Figure 3**. Emergency shutdown of the drill drive when the power consumption is exceeded

Figure 4 shows the results of a study of the data transfer model from an oil well. The upper graph of the model shows the simulation of the transmission of the original signal in the submerged telemetry block. Logical voltage levels are represented by two signals: level 0 corresponds to the opening of the key (on the graph yellow meander) and level 1 corresponds to the closure of the key (on the purple meander graph). The lower graph of Figure 4 shows the meanders of the received signal in the ground control unit. Thus, the possibility of transmitting a digital signal over a wireline cable is shown. The next task was to determine the possibility of evaluating the transmitted information when the channel is noisy.
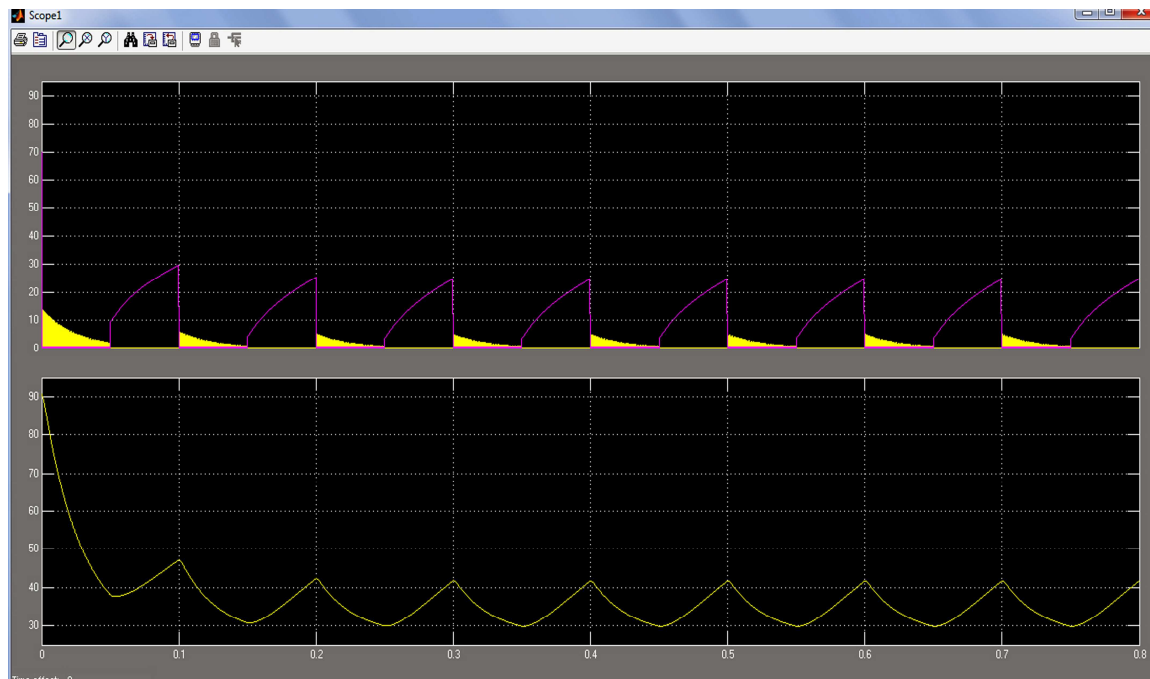


**Figure 4**. Results of the experiment for modeling the transmission / reception of logical signals: the upper graph of the model shows the simulation of the transmission of the original signal in the submerged telemetry block; the lower graph shows the meanders of the received signal in the ground control unit

In the work, the parametric modulation of the signal was studied in the simulation of the experiment (the length of the carrier sequence / noise). Typical types of modulations are known: analog, frequency, phase, etc. When working in noisy transmission lines, various filters are used to extract a useful signal: a moving average filter, a digital cosine filter, bandpass filters, etc. [12]. In this paper, the authors propose a technique for modulating a signal obtained by synchronously overlapping an information binary signal onto a carrier coded sequence using the inverse addition operator modulo 2 (Figure 5). The length of the carrier sequence was coded from 4 to 7 bits.
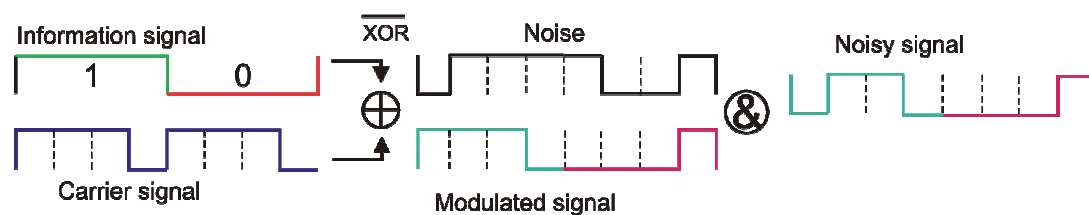


**Figure** 5. The modulation scheme of the signal

The choice of the length of the carrier sequence L was determined by three parameters: the amount of information encoding n, the quality of the recognition of the information signal k, and the noise of line (the number of changed bits) $L = f$ ($n$, $k$, $sh$). Table 1 shows an example of encoding information signals for $L = 4$. That is for $L = 4$, $2^4 = 16$ signals can be encoded.

**Table 1.** Example of encoding information signals with $L = 4$

| № | Encoding | Measured variable |
|---|----------|-------------------|
| 1 | 0000 | Temperature |
| 2 | 0001 | Pressure |
| 3 | 0010 | Vibration |
|   | … | … |
| 16 | 1111 | Insulation resistance |

The resistance to noise was evaluated by the recognition of a modulated signal. The recognition algorithm consisted in applying a mask of the modulated signal to the noisy one using the correlation analysis of the pair valuesof the Boolean variables. The results of the experiment for determining the dependence of the length of the carrier sequence / noise are shown in Table 2.

**Table 2.** Results of the dependence on the recognition of the information signal (length of the carrier sequence / noise)

| length $L$, bit | Noise $sh$, bit | Correlation coefficient | Level Recognition |
|-----------------|-----------------|-------------------------|-------------------|
| 4 | 1 | 0.75 | Good |
| 4 | 2 | 0.5 | Unsatisfactory |
| 6 | 2 | 0.67 | Satisfactory |
| 7 | 3 | 0.57 | Satisfactory |

The results of the experiments showed that when using a parameterized modulated signal with a correlation coefficient of more than 0.5, a satisfactory reception / transmission of information using a logging cable in oil production is achieved.

## 4. Conclusion

Based on the presented model, the Simulink SimPower Systems module created a virtual model of the data medium of the submersible telemetry system. To suppress the interference of a digital signal, a filter based on signal modulation using the XOR operator was developed and studied. This model can be used later in the design of experiments to recognize the transmitted signals from the well. To monitor and control the electric drill drive, the software for programming the OMRON controller has been developed.

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