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Development of a Descending Commands Unit for the Downhole Telemetry System via the Hydraulic Communication Channel

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Abstract

In this article the design of a prototype of descending commands unit is presented. At the Experimental drilling equipment plant of Industrial University of Tyumen the development of rotary steerable system is conducted. Within this project in order to enable the transmission of commands from the ground part of equipment to the downhole complex, which includes the rotary steerable system, various options of the descending commands unit were considered and studied. The hydraulic communication channel has been selected for implementation of the descending commands unit. On the basis of calculations of the optimal parameters - the value of the control signal, the interval between pulses, the range of the recorded pressures - the prototype of descending commands unit with the software was developed, compatible with existing hardware and software.

Keywords: downhole, drilling, rotary steerable system, descending commands unit, hydraulic channel.

INTRODUCTION

Currently, when drilling wells rotary steerable systems (RSS) are increasingly being used to allow for a controlled wellbore curvature with a given intensity and continuous rotation of the drill string. This is their main difference from traditional bottom-hole assemblies (BHA), managing which for directional drilling it is necessary to stop the rotation of the drill string for the entire time of drilling a directional section. This can lead to poor cleaning of the wellbore from cuttings, problems with ensuring uniform load on the bit, as well as a substantially increased risk of differential sticking of the drill string compared to the RSS. Another important feature of the RSS application not including a power section is a reduction in the operating pressure of circulation, as opposed to using positive displacement motors (PDM).

All these features take BHA incorporating a RSS to a level of new generation drilling techniques, and help to achieve the following advantages [1]:

- increasing the target depth of the bottom hole;
- reducing risks of complications of open wellbore when drilling intervals in complex geological conditions;
- reducing risks of differential sticking of the BHA;
- ensuring a "smoother" profile of the well path that allows the use of complex systems of horizontal well completion.

MATERIALS AND METHODS

Analysis of the bottom-hole and wellhead equipment communication problem

RSS are generally integrated with downhole telemetry systems (DTS). DTS have an on-board controller and ensure the delivery of data to the surface from well logging devices and the telemetry parameters of the downhole equipment complex (LWD) [2]. The data is transmitted mainly via hydraulic or electromagnetic communication channels. RSS, in turn, can also carry a digital controller to provide feedback for control function that is the ability to modify the drilling direction and intensity of the wellbore curvature on a preset program or by receiving commands sent from the ground part of the complex [3].

RSS currently presented on the market are mainly are produced by leading foreign oil and gas service companies, but domestic manufacturers, in the framework of import substitution programs, are developing similar systems and retrofitting existing DTS to enable integration with new devices and systems.

In particular, the development of RSS is conducted at the Experimental drilling equipment plant in Industrial University of Tyumen (IUT). Within the project, to enable the transmission of commands from the ground part of equipment to the downhole complex, which includes the RSS, various options of the descending commands unit (DCU) were considered and studied.

Possible data transmission channels to the bottom hole are: hydraulic, electromagnetic and vibration.

The electromagnetic channel has been excluded from the development due to the fact that it usually requires DTS with the electromagnetic transmission channel to the surface, then the signals are split according to the transmission frequency, and the main difficulty is to provide enough signal power. There are such systems in Russia, but their relative proportion is small, as they have limitations in depth and lithology of the geological section and with increasing depth it becomes necessary to reduce the frequency of electromagnetic signals, which makes DTS with the electromagnetic channel lose their advantage in transmission rates. From vertical depths of about 2200-2500 meters, the DTS transmission rates via hydraulic and electromagnetic channels are comparable. Note that as reserves are being development, the depths of wells tend to increase as the complexity of geological sections increases.

The vibration method uses available on-board RSS electronics vibration sensors along three axes. Thus, it is possible to receive the useful signal with respect to certain gaps between the vibrating action (displacement or rotation). Typically, the transmission is performed by cyclic periods of rotation and immobility of the drill string. The disadvantages of this method is the need to periodically stop the drilling tool rotation, which leads to the risk of sticking, and signaling complexity during drilling if there is circulation. .

The hydraulic channel is used by the overwhelming majority of DTS to transmit signals to the surface, because, despite its shortcomings, it is sufficiently stable almost at any depth, easy to implement and has a fairly broad scope of performance. The same applies to the descending communication channel DCU - DTS (RSS). It should be noted that the DCU can be used to transmit commands both to the RSS and DTS, depending on the degree of integration of the downhole equipment. The RSS receives commands with settings on the direction of drilling, the intensity of angle buildup, maintenance or modification of these parameters, as well as service commands. The DTS may receive commands changing the parameters of the DTS pulser, switching between communication protocols, stopping for batteries saving during working through and flushing, staring, etc.

Thus, the hydraulic communication channel has been selected for the implementation of the DCU. For the technical implementation of communication through the selected channel two half-sets should be developed, produced and tested: the ground part (the DCU itself), and the downhole part - executed as a differential pressure gauge that measures the differential pressure of the drilling mud inside the drill tool and the annulus, between the tool and the borehole wall (in-tube and annular pressures).

Calculation of the DCU parameters

To implement the wellhead part of the half-set, the DCU is installed in a high-pressure manifold. It is functionally required to form negative pressure pulses in the drill pipes. It is controlled by commands generated by the software of the upper level, which is installed on a data acquisition system (DAS) computer and is used for signal encoding, according to the received transmission protocol.

At the initial stage of DCU development it was required to calculate the sectional diameters of chokes for pressure relief at different flow rates of washing liquid in manifold line per second by 20-40% of the operating pressure of the circulating drilling system.

To solve this problem a model of a nonstationary flow of liquid through the pipe was used, described in [4,5]. Nonstationary isothermal motion of a compressible fluid in the pipe is described by the following system of equations:

$$\begin{cases} \rho_t + u\rho_x + \rho u_x = 0; & \begin{pmatrix}\text{Continuity}\\ \text{equation}\end{pmatrix} \\ \rho(u_t + uu_x) + (P_x) = \alpha; & \begin{pmatrix}\text{Conservation}\\ \text{of momentum}\end{pmatrix} \\ (P_t + uP_x) - a^2(\rho_t + u\rho_x) = 0. & \begin{pmatrix}\text{Conservation}\\ \text{of energy}\end{pmatrix} \end{cases} \quad (1)$$

Where $u -$ the flow rate of liquid, m/s; a – the speed of sound in nitrogen, m/s; $\alpha -$ the stationary pressure gradient $\alpha = \rho g \sin\theta - \frac{f\rho u|u|}{2d}$, Pa/m; t – the time, s; x – the spatial coordinate, m, $f -$ the pressure loss factor of friction for straight pipes, ρ- density, kg/m^3; g- the acceleration of gravity, m/s^2, d – the pipe diameter, m;

By the method of characteristics the system of equations 1 takes the form of ordinary differential equations 2-4

$$\frac{dP}{dt} + [\rho\alpha]\frac{du}{dt} = +a\alpha \text{ provided that } \frac{dx}{dt} = u + a, \quad (2)$$

$$\frac{dP}{dt} - [\rho\alpha]\frac{du}{dt} = -a\alpha \text{ provided that } \frac{dx}{dt} = u - a, \quad (3)$$

$$\frac{dP}{dt} - a^2\frac{d\rho}{dt} = 0 \quad \text{provided that } \frac{dx}{dt} = u. \quad (4)$$

Equations 2-4, respectively, describe the propagation of expansion waves, compression waves and substance flow and together constitute a system of equations that is solved by the modified Euler method with recalculation. A channel, along which the mud flow was conducted, was the drill string from the discharge point (the first calculation unit) to the drill bit (the last calculation unit). A calculation step with respect to time was 0.1 s, which satisfies the Courant criterion.

The initial data for calculation:

1. The drilling mud circulating system. The pressure at the bottom hole is equal to the hydrostatic pressure of mud in the annulus.
2. The mud density is 1.2 kg/l.
3. The well is vertical; the depth is 3000 m.
4. The equivalent diameter of the bit is 13 mm.
5. At the initial moment the mud flow mode is set.
6. The inner diameter of the drill string is 100 mm.
7. Mud pump capacity rates are 60 l and 15 l.
8. At 60 l/s, the pumping pressure is 225 atm.
9. At 15 l/s, the pumping pressure is 21 atm.

As a result, the following data were obtained. At the rate of 60 l/s pressure drops by more than 48.6 percent per second when retracting 85% of the flow from the drill string via the discharge line, and the choke diameter must be 22.0 mm. At the rate of 15 l/s pressure drops by more than 63.6 percent per second when retracting 50% of the flow from the drill string via the discharge line, which fits into the allowable range (above 40% and below 100%), the calculated choke diameter - 9.2 mm. Figure 1 is a graph of the pressure drop at the wellhead when discharging 85 percent of the drilling mud at a flow rate of 60 l/s.

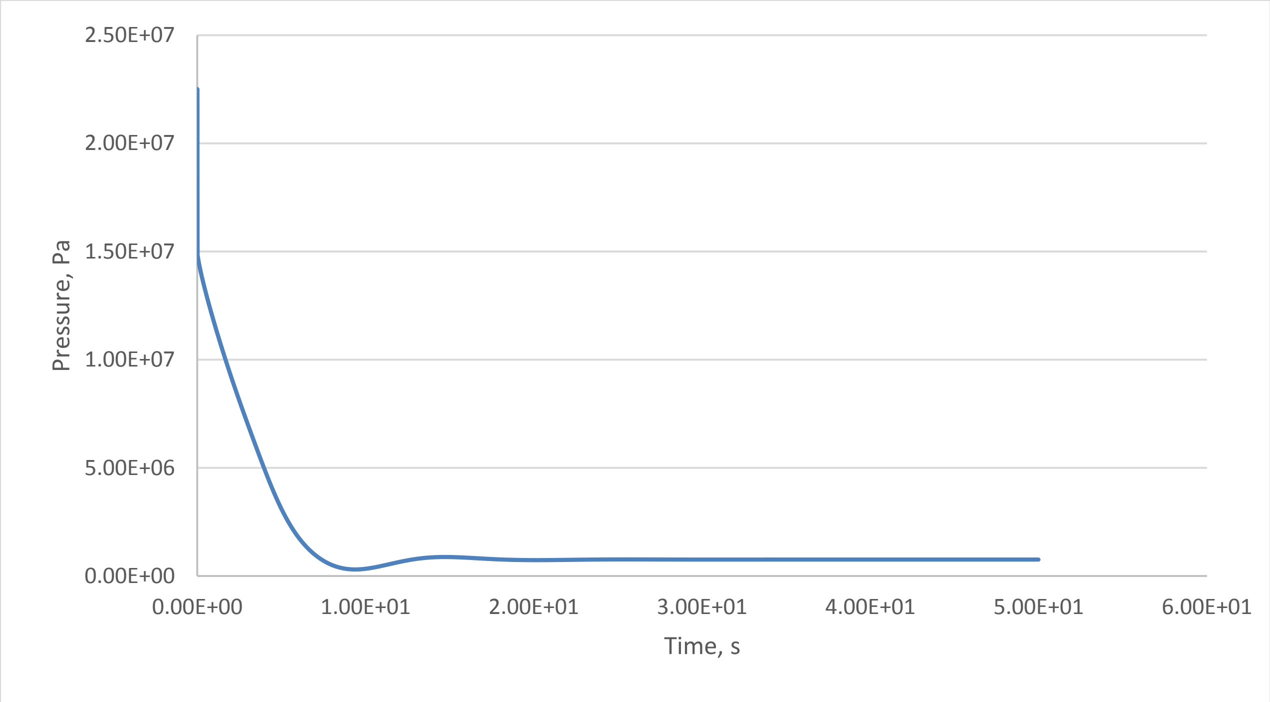

Figure 1: Graph of pressure at the wellhead on time when discharging 85% of mud via the DCU. The capacity rate is 60 l/s.

According to the calculation, the pressure at the wellhead stabilizes in 30 sec., but the required 40% pressure pulse is generated in less than a second after the discharge (discharge occurs at the first calculation step, i.e. at *t*=0.1 s).

Figure 2 is a graph of the pressure drop at the wellhead when discharging 85% of mud at the rate of 15 l/s.

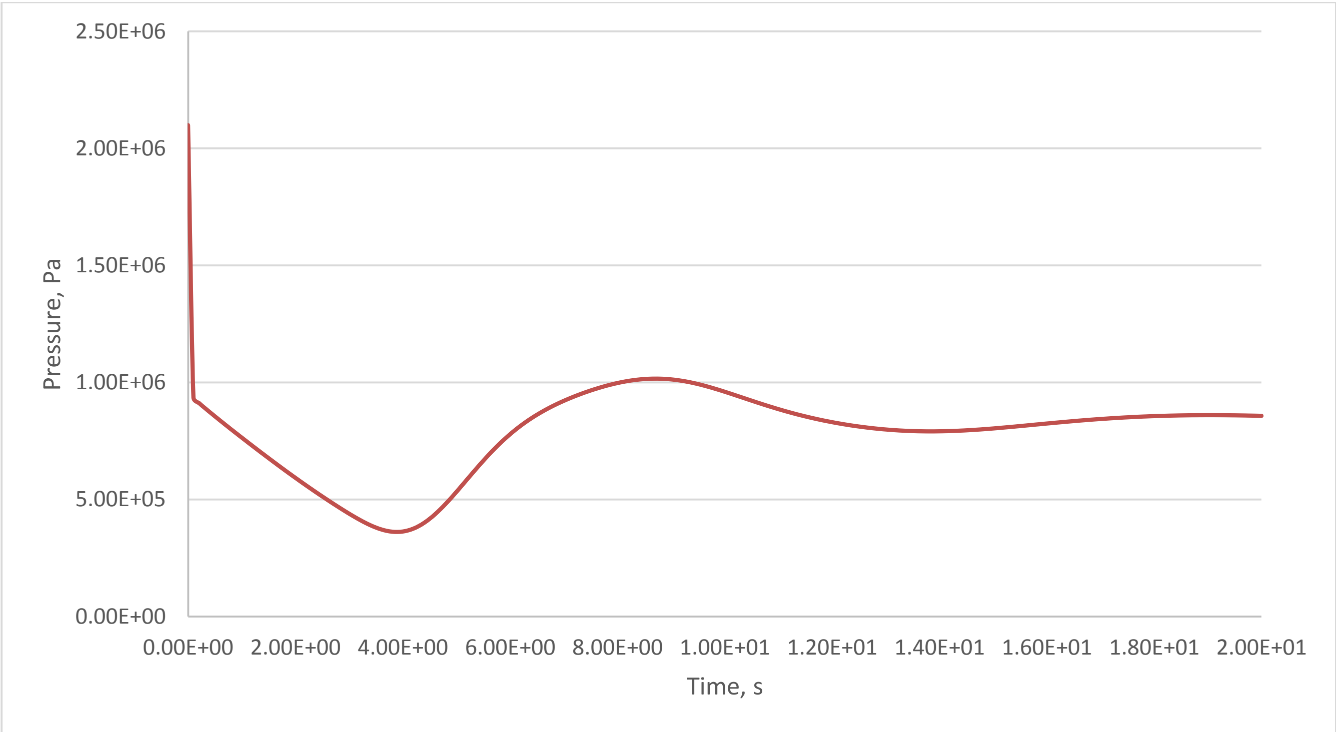

Figure 2: Graph of pressure at the wellhead on time when discharging 85% of mud via the DCU. The capacity rate is 15 l/s

In this case, the graph clearly shows hydroblow waves, as a change in the discharge pressure is comparable in magnitude to the pressure losses in the system and is not lost on the scale. Here, the required pressure drop of 40% at the wellhead is also achieved in less than 1 second, which allows achieving the desired characteristics of the DCM.

RESULTS AND DISCUSSION

Development of the DCU prototype

The bottom-hole part of the half-set, as noted above, is represented by a differential pressure gauge capable of detecting pressure drop pulses created by the DCU - the so-called "negative pulses". Then, the device controller decodes the received pulse sequence, checks for parity and transmits to the RSS (or DTS) controller as a command, according to the protocol. This device is marketed as a separate downhole module and can be used both in the RSS and DTS as a device for measuring pressure while drilling (PWD). Such sensors are used in the imported analogues (PWD) to calculate the degree and quality of the wellbore cleaning from cuttings, problems in the wellbore by type of caving and caking, loading characteristics of the BHA, and other parameters.

To simulate the formation process of negative pressure pulses and the debugging of information transmission in a pair "encoder-decoder", at the IUT-based Experimental drilling equipment plant the DCU prototype was designed and assembled (fig.3). Structurally, the unit consists of a frame, on which a ball valve with a pneumatic actuator and electromagnetic valve is rigidly mounted, a manual control unit, a remote control unit based on a personal computer (fig. 4).

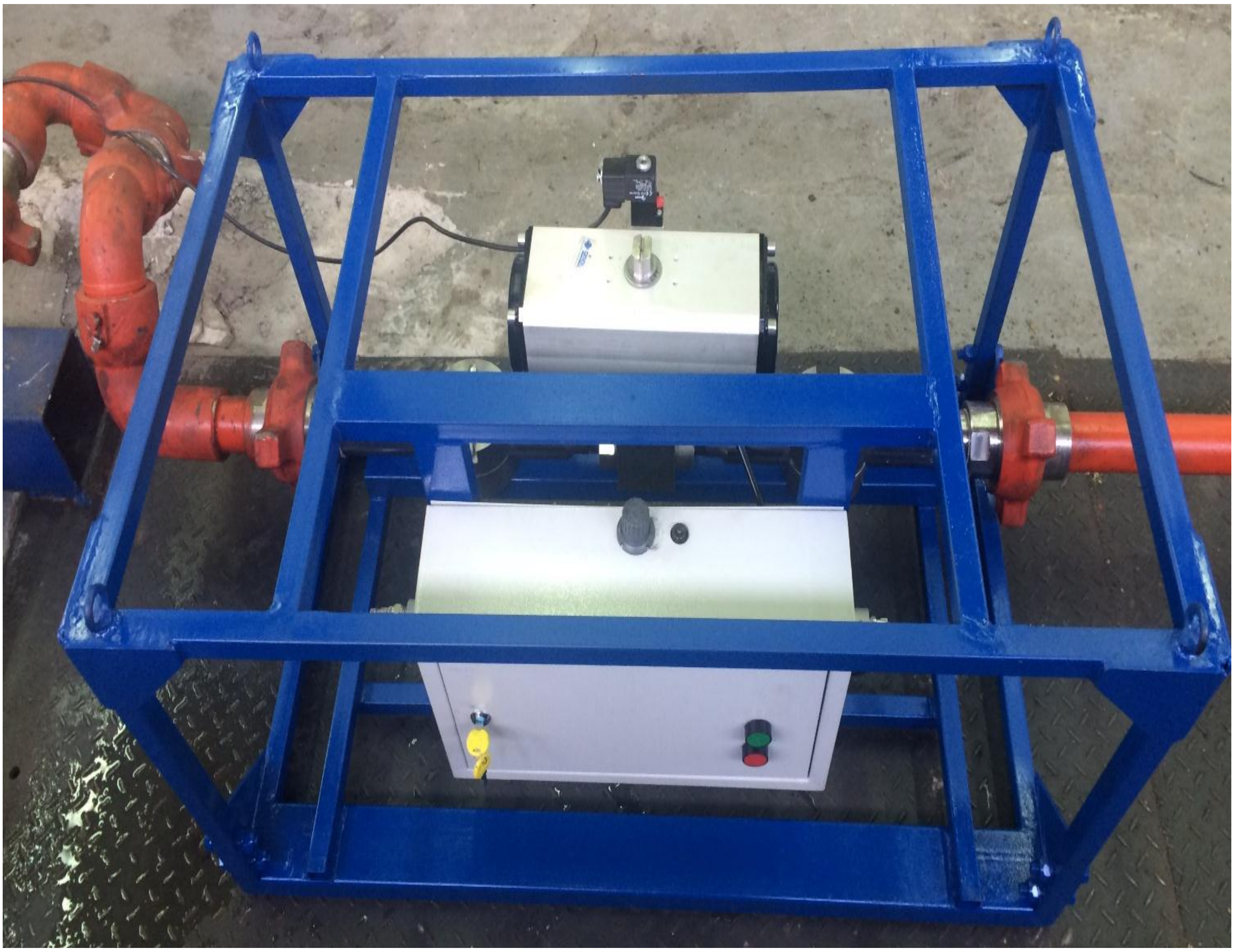

Figure 3: Assembled DCU prototype

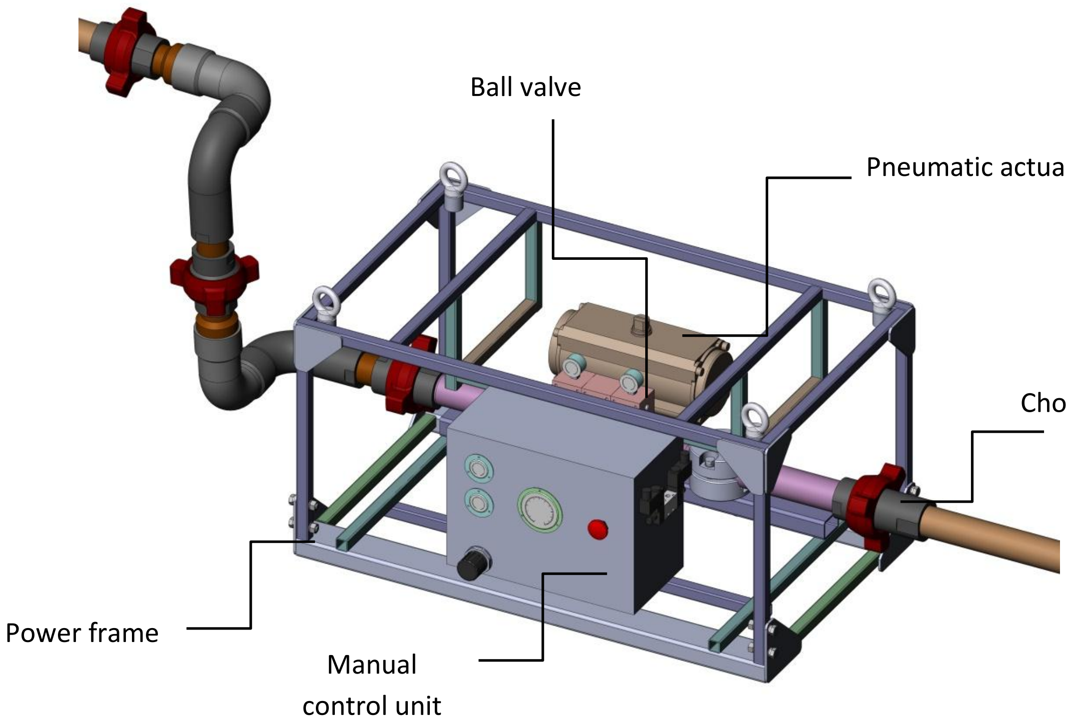

Figure 4: Scheme of the developed DCU

To control the DCU, software was developed consisting of two parts - an encoder to control the DCU, and a decoder (emulation of the downhole equipment to detect commands).

At the beginning of the package there is a sync sequence, or a block of initialization pulses to transfer the receiving part of the DTS into a standby mode, frequency and phase synchronization between the encoder and decoder.

The encoding of information is carried out by changing the pulse repetition time, pulse code keying (PCK) is used, the signal arrival time corresponds to its numeric value in a hexadecimal format, then the following value, and so on until the end of the package. To distinguish between the transmitted values and the sync pulses, and to minimize scrap during transmission, a minimum time interval between pulses is set (in the sync sequence than the time between pulses is smaller). Upon receiving the package and its decoding, status confirmation is sent (in the prototype - sending is emulated), after which the operator makes a decision on the correctness of the received combination and the need to send an additional package. Time intervals, pulse width and the carrier frequency for the time of the experiment may have a variation set by the operator to verify the quality of detection and decoding. Both work on the prototype using a complete set of sensors and emulation of hydraulic lines are provided. The software provides analysis and statistics of errors arising during transmission - reception.

The developed software for DCU control allows the operator to select a command from the list, the parameter values are added if necessary, frequency variation and amplitudes within the package. Then, the software converts the entered value in PCK and delivers the control pulses to the port of a personal computer. After conversion in the DAS block, the control pulses are delivered to the electromagnetic valve of the pneumatic actuator, the ball valve opens (for the time of the pulse length), the pressure in the manifold line drops due to the diversion of the flow through a calibrated choke. The pressure sensor receives the generated impulses and transmits them to a decoding half-set that replaces the downhole tool.

CONCLUSIONS

1. A goal of the research work has been reached, which consists in determining the optimal parameters: the value of the control signal, the interval between pulses, the range of the recorded pressures ensuring maximum accuracy of command transmission by negative pressure pulses.
2. Further development of the software will aim at working out algorithms of the downhole half-set operation, a decoder, to enable modification of reception parameters autonomously and automatically based on the distortion arising in the real hydraulic channel that depend on the parameters of the mud and change with depth.

3. The developed DCU prototype being, in essence, an actuating mechanism can be connected to the existing hardware and software by means of integrating devices via standardized signaling channels to ensure communication with the surface, DTS and RSS of various manufacturers.

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