Elaboration of Receiver Unit of Azimuth Acoustic Correction System

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***Abstract*—The paper describes a method of azimuth acoustic correction of an inclinometer for oil and gas wells in high-latitude areas where usual gyroscopic and ferromagnetic sensors are inefficient because of significant errors. An embodiment of the method and options for units are presented. The focus is on a scheme of acoustic receiver unit of the system and it main functions such as downhole acoustic signal recording and data transmitting from downhole to wellhead. A comparison of analog and digital variants for data transmission is presented and justification for selecting the analog variant as preferable is given. The electronic scheme of the receiver unit as the preferable variant is described and estimates of operability of the unit are given.**

Keywords — borehole navigation; inclinometer; acoustic receiver; Sallen-Key filter

I. Introduction

For drilling oil and gas wells, especially with use of cluster drilling methods, the issue of accurate determining of drill assembly position in the Earth stratum is very important. At present gyroscopic and magnetic sensors included into an inclinometer are used to obtain information about the position of the drilling assembly. However the area of application of these sensors is limited. For example in the high-latitude areas where the horizontal component of the Earth's rotation becomes small, in order to obtain acceptable accuracy of positioning, instruments significantly more complicated and expensive with stable operation at high temperatures and super-large shock loads and vibrations are required. Magnetic sensors become inefficient due to large magnetic declination for these areas. In this case there is an interest in alternative methods of positioning of the drill assembly. One such method of navigation is that of azimuthal acoustic correction of an inclinometer. The system and particularly its unit – acoustic receiver will be described in this paper.

II. System of Azimuth Correction of an Inclinometer

A. Scheme of system of azimuth correction

To implement the method of azimuthal acoustic correction [1], a scheme that involves sources of acoustic radiation and receivers has been chosen. These several sources of acoustic radiation have to be placed at a certain distance from the wellhead at equal distances from the design drilling plane. Acoustic receivers which record radiation from acoustic sources are located on the drilling assembly. Such an arrangement of units makes it possible to eliminate noise from the operation of the mechanisms existing on the Earth's surface, to simplify the issue of power supply to acoustic sources and also to use accelerometers located in an inclinometer as receivers of acoustic radiation [2]. The scheme of the azimuth correction system is shown in Figure 1.

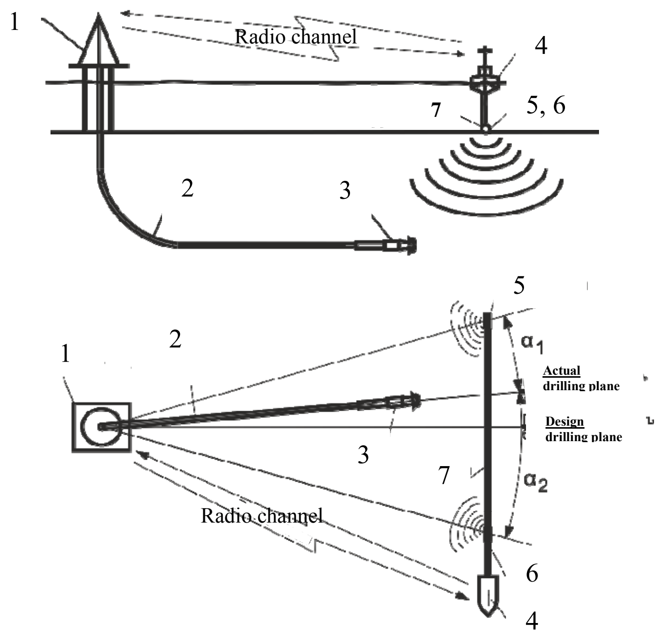

Fig. 1. Scheme of the system of azimuth acoustic correction of an inclinometer. 1 – offshore platform; 2 – drill string; 3 – drill assembly with an inclinometer; 4 – a vessel; 5, 6 – sources 1 and 2 of acoustic radiation; 7 – plastic pipe.

Figure 1 shows an offshore platform 1 which is used for cluster drilling, the drill string 2 and the drilling assembly 3, located at the bottom of the well and containing an inclinometer with accelerometers. Acoustic sources 5 and 6 together with power cables and source control systems are

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placed in a plastic pipe 7, which is laid by the vessel 4 to the sea bottom some distance from the wellhead. The pipe is located in a plane perpendicular to the designed drilling plane. Distances from the designed drilling plane to each acoustic source are equal. If there is an azimuthal deviation of the actual drilling plane from the design plane the distances differ from each other. One-sided displacement of sources and receivers relatively to the wellhead and their location in a narrow sector increase the probability of finding the measurement system in area with a homogeneous soil structure. By defining distances from the acoustic sources to the inclinometer it is possible to determine the angle $\Delta\alpha$ ($\Delta\alpha = \alpha2\text{-}\alpha1$) and implement a correction of readings of inclinometer instruments which determine the azimuthal position.

B. Acoustic generators

The distances from the drilling assembly to acoustic sources compared with global positioning systems can be determined by time delay or by attenuation of signals during propagation between acoustic sources to the receiver through the Earth's crust. A reliable signal can be obtained only in the case of a powerful acoustic radiation exciting the Earth's crust. The use of time delay to determine distances between acoustic sources and receiver is not efficient [2] and the focus is on the attenuation of the signal during its propagation. In the embodiment of the azimuth correction system, the acoustic receivers are placed on the sea bed where small acoustic noises occur when the drilling is stopped. In addition, precision accelerometers are often used in inclinometers, for example Q-flex type, with high resolution and capable of distinguishing a small acoustic signal. All this makes it possible to use low-power acoustic sources in the correction system. The acoustic signal is formed as a continuous harmonic vibrational radiation, which is created by a flexible rotating shaft. The design of the acoustic source is shown in Fig. 2.

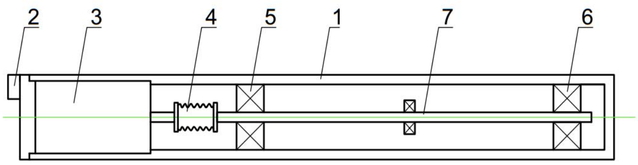

Fig. 2. Design of acoustic source

In Fig. 2 is shown:
1 – acoustic source frame;
2 – vibrational sensor;
3 – DC motor with control system;
4 – bellows coupling;
5, 6 – spherical bearings;
7 – flexible shaft with bearing in central for limiting maximum deformations of the shaft.

When power is applied to the motor, the shaft is driven into rotation. The shaft has a small initial imbalance and when the angular velocity is set the oscillations develop. The amplitude of oscillations sharply increases as it approaches resonance. The frequency of the first form of bending vibrations of the shaft should be chosen sufficiently low (15-20 Hz) in order to ensure a small attenuation of the acoustic wave for it propagation through the crust. In the system there are two simultaneously operating sources with the same intensity of acoustic radiation and different resonance frequencies of oscillations of the flexible shaft (17.3 Hz and 18.4 Hz). Sources operate in the regime of continuous vibration for a period of time up to 50 seconds. During this time an array of data for measured accelerations is formed in the memory of the inclinometer and the spectra of the received signal are calculated. In the spectra computation the effect of accelerometer noise drastically decreases as the measurement time increases. Thus on the basis of attenuation of acoustic signals on the way from the vibrational acoustic sources to the inclinometer the deviation of the drilling assembly from design position of the drilling plane is determined.

III. ACOUSTIC RECEIVER UNIT OF THE SYSTEM

A. Options of signal detecting

Several options for implementing the electronic circuit to calculate the acoustic signal recorded by the accelerometers and the further transmission of this signal from the face to the drilling platform were considered. The first option involved the recording and transmission of an analog signal directly to the drilling platform; in the second variant it was envisaged to record and convert the analog signal into a digital code and transfer the digital signal to the drilling platform.

The analog signal transmission option has such advantages as a simple electrical circuit for the receiver unit, relatively simple transmission of an analog signal over a wireline cable (this requires linear power amplifiers with a large permissible output current and short-circuit protection). However due to the limited number of channels in the wireline cable when the analog signal is transferred to the platform it becomes difficult to rearrange and control the band-pass filters located in the downhole to record signals from different acoustic sources. In addition an issue requiring special attention is that of interference suppression in a long communication line since their level on the 5-8 km line can be 10-100 times greater than the useful signal.

In contrast to analogue signal transmission, a digital communication channel allows to easily switch receiver channels accelerometers with help of digital control of bandpass filters. In addition, in the digital transmission of a signal, it is much better to suppress an unnecessary signal and to avoid interference when data is transmitted via a wireline cable to the platform. However this option requires special methods for transferring a digital signal through a wireline cable, development and debugging of highly reliable software for the microprocessor to run uninterruptable programm on a borehole assembly. In combination there is a lengthy and costly process. In this connection method of transmitting of the analog signal from the downhole to the platform was chosen as basis.

B. Implementation of signal detecting unit

To implement the analog option of signal acquisition and transmission, a scheme of electronic units located in the downhole was developed for primary processing of the acoustic signal and its transferring to the drilling platform. The diagram of the measuring channel is shown in Figure 3.

In connection with frequencies 17.5 Hz and 18.3 Hz of oscillations of acoustic sources it is proposed to use a circuit which includes an instrument amplifier and two Sallen-Key topology filters. The second unit – filter with Sallen-Key topology of the first order should implements a high-pass filter with a cutoff frequency equal to 5-7 Hz. The third unit – third-order filter with Sallen-Key topology based on the Chebyshev

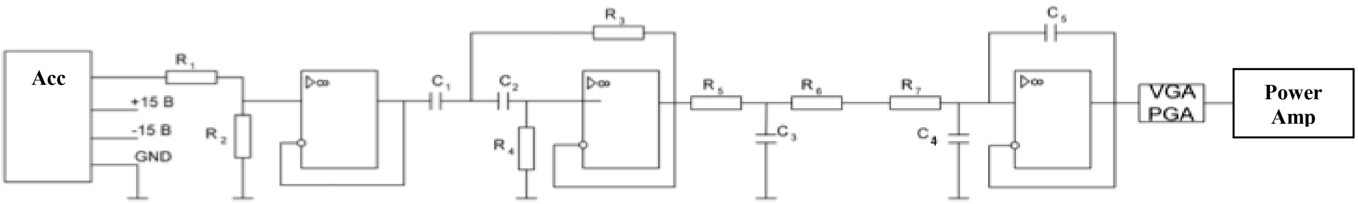

Fig. 3. Structure scheme of a measuring channel of acoustic receiver of the system of azimuth correction of an inclinometer.

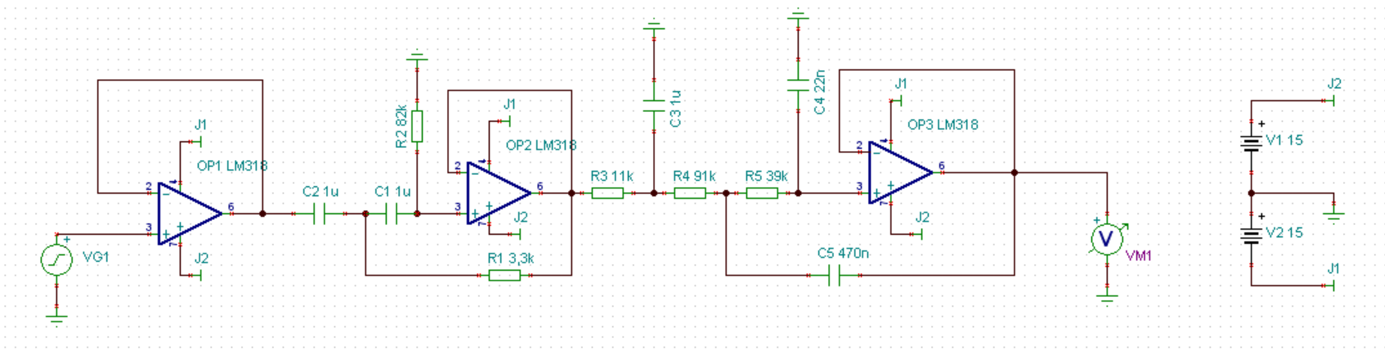

Fig. 4. Electric scheme of measuring channel of acoustic receiver of the system of azimuth correction of an inclinometer.

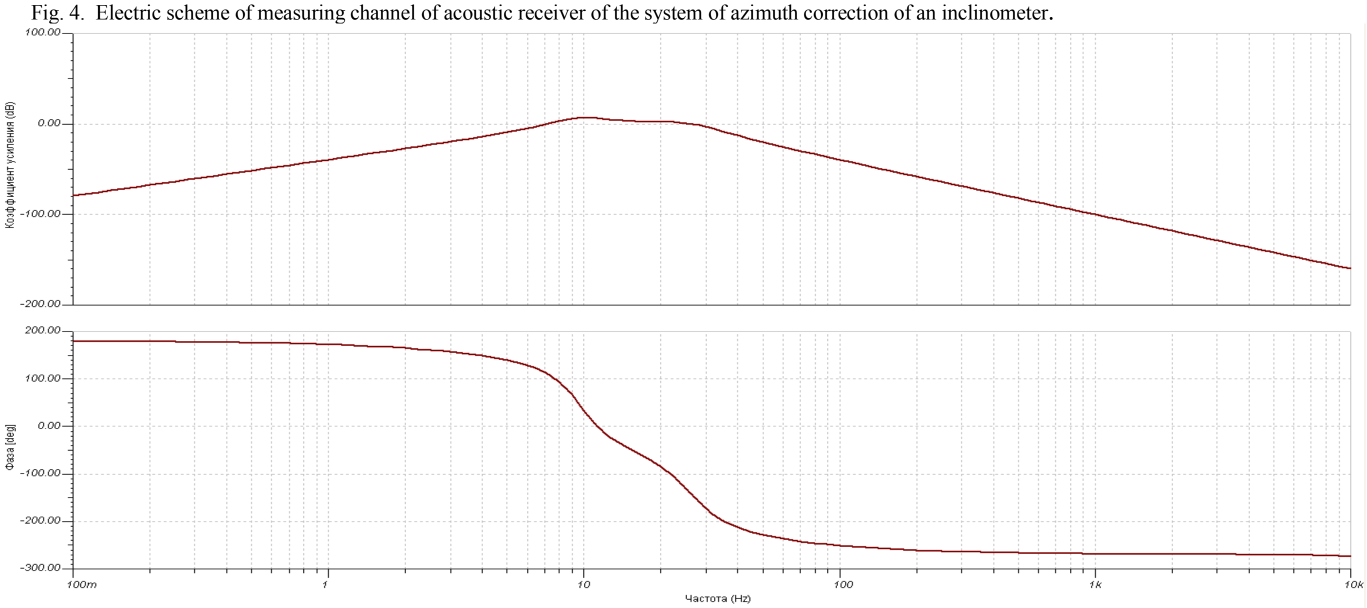

Fig. 5. Frequency response functions of measuring channel of acoustic receiver.

filter implements a low-pass filter with a cutoff frequency equal to 25-30 Hz. To transmit the signal via borehole wireline a variable gain amplifier and a power amplifier are included into the circuit. The scheme allows the initial recording and processing of the acoustic signal from the acoustic source and also to transfer data for the final processing to the drilling platform. The principal electrical circuit of the measurement channel is shown in Fig. 4. On the second cascade for implementing cut-off frequency f is equal to 10 Hz and *Q-factor* equal to 0.7 RC-elements can be calculated as:

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{R_3 R_4 C_1 C_2}}; \quad \frac{2\pi f_0}{Q} = \frac{C_1 + C_2}{R_4 C_1 C_2}$$, where

$C_1 = 21\mu F;\ C_2 = 1\mu F;\ R_3 = 3.3k\Omega; R_4 = 82k\Omega$

For the third-order filter with Sallen-Key topology parameter f is equal to 25 Hz and *Q-factor* is equal to 0.7. In this case RC-parameters can be set as follow: $C_3 = 31\mu F;\ C_4 = 22\mu F;\ C_5 = 470nF;\ R_5 = 11k\Omega;$ $R_6 = 91k\Omega;\ R_5 = 39k\Omega.$

By selecting RC-parameters for each cascade the required frequency response functions (amplitude and phase) of the receiver can be formed. The frequency response function necessary for use in acoustic receiver is shown in Figure 5.

It can be seen from the figure a band-pass filter actually obtained a signal transmission with frequencies range from 10 Hz to 25 Hz that is sufficient for registering an acoustic signal from vibrating sources and proper operation of the system of azimuth acoustic correction.

IV. References

[1] S.F. Konovalov et. al. Patent RU 2619563 "Method of azimuth acoustic correction". 16.06.2017. Priority date 18.03.2015.

[2] S.F. Konovalov, D.V. Mayorov, V.E. Chulkov, et al. "System of azimuth acoustic correction of an inclinometer" Proceedings of XXII Conference on Integrated navigation systems. Saint-Petersburg, pp. 363-367, May 2015.