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INTEGRATED IMPROVEMENT OF THE EFFICIENCY OF COMPUTER CONTROL SYSTEM OF SPATIAL ORIENTATION SETTINGS OF DRILLING FACILITIES

Purpose. Improving the efficiency of the system by increasing the accuracy in determining the drilling objects' spatial orientation, as well as adjusting the system components to more accurately isolate the information signal from the angle transducer.

Methodology. A comprehensive increase in the angle transducer accuracy is based on taking into account the influence of factors and errors in determining the drilling object's spatial orientation, as well as a possibility of smoothly tuning the characteristics of the receiving part due to the departure of the information modulated signal frequency from the angle transducer.

Findings. Given the converters' operating condition, the error in measuring the zenith angle (deviation angle from the vertical) does not exceed 0.3°, the installation angle of the deflector is 3°. In addition, restructuring the frequency-dependent components characteristics of the system's receiving part allows one to make changes quickly and improve the overall system.

Originality. A comprehensive solution to the problem of increasing the control system efficiency is to increase the converter characteristics, by taking into account its errors and operating conditions, as well as increasing the smoothness and tuning the characteristics efficiency of the receiving part, due to the possibility of calculating the transfer function coefficients using simplified ratios, which will greatly simplify the process of processing information and improve the quality of inclinometric work.

Practical value. This complex solution is brought to the design, manufacture and experimental converter verification, and algorithms and programs for tuning frequency-dependent components are proposed and brought to implementation.

Keywords: *inclinometric sensors, band-pass filter, peak frequency, amplitude-frequency response, phase-frequency response, transfer function coefficients*

Introduction. In the oil and gas industry, there has been an increase in directional and horizontal drilling [1, 2]. This is mainly due to repeated "re-drilling" of areas with a compacted well grid [3]. It is economically advantageous to repeat "re-drilling" on prepared sites, which saves 20–45 % of costs for their equipment. Besides, a rough terrain, power lines, pipelines, a great number of settlements and industrial constructions often do not allow setting up a drilling rig directly above the project point. Hence, the necessity to drill directional wells with rather big displacement of the mouth from the design point (up to 700 m and more) appears [4].

In addition, drilling horizontal wells is appropriate when developing limited lenticular formations and when uncemented and unstable to fracture formations are opened. It should be noted that drilling horizontal wells involves combining large- and medium-radius curvature well profiles for better reservoir drainage, especially when drilling offshore from fixed drilling platforms. From such a platform, a cluster of directional wells is drilled, with the number of wells in the cluster ranging from 18 to 36 [4].

Strict requirements to maintain the design profile of a well narrow the access range to which it must fall and prevent wellbores drilled from the same platform from crossing. Periodic wellbore trajectory measurement can lead to significant deviations of the actual wellbore profile from the design wellbore with the corresponding consequences and high material costs [5]. For example, a 15 m error in wellbore deviation may result in incorrect reservoir thickness estimates and complications. Well re-entry costs do not exceed 60 per cent of the cost of drilling a new well [6].

Continuous monitoring and adjustment of the borehole trajectory is thus of particular relevance and importance in the face of ever-increasing directional drilling and increased rate of penetration.

However, the drilling of directional wells requires a lot of additional equipment, complex technological operations, and, it should be emphasised, is associated with a large amount of inclinometric work – work to measure the parameters of the well.

To control the position of the borehole, the drilling process must be stopped periodically and geophysical inclinome-

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ters measuring inclination and azimuth must be lowered into the borehole. To force a change in trajectory, a deflector device is built into the drilling tool, the position of which is measured by instruments lowered on a cable. Accurate borehole trajectory determination requires multiple measurements, which amounts to up to 10 % of the borehole's design value [6]. Besides, for deviated and branched-horizontal wells, delivery of measuring devices to the bottomhole and their evacuation is a complicated operation consisting in removal of the whole tubing string and lowering of inclinometer device into the borehole on special tubing. The time required for inclinometric work is two to four times longer when correcting the direction of the wellbore.

However, monitoring and correction of the borehole trajectory can be carried out continuously without stopping the drilling process. In this case, the transducers with established communication channel between them and ground control facilities, should be located as a part of the drilling tool, and promptly provide necessary information about spatial angular position of the drilling tool and position of the deflector for prompt intervention if the borehole trajectory differs from the design one.

The spatial orientation parameters of the borehole trajectory are controlled by a computerised spatial orientation control system (CSOCS). Increase in CSOCS performance indicators is determined by availability of technically perfect means for continuous control of orientation parameters, which is reflected directly in the name of such systems abroad – MWD (Measurement While Drilling). Application of such systems improves quality of well penetration, saves material and time and helps to avoid emergency situations [8].

The creation and introduction of such systems in our country is hampered by the fact that mass-produced and existing inclinometer designs cannot withstand vibration and shock overloads (50 g) accompanying drilling, as well as temperatures up to +120 °C. The diameter of the inclinometer's protective casing should not exceed 40 mm. Besides, the inclinometers' disadvantages are inaccuracies in determining parameters of the borehole trajectory, as well as their not being so reliable during drilling. The lifetime of inclinometer transmitters without repair does not exceed 100 operating hours. This does not allow using them as a part of computer information management system (CIMS) during drilling process and cannot increase drilling productivity. Therefore, it is necessary to develop vibration-proof inclinometer transducers (IT) with improved technological and operational characteristics.

The technical characteristics analysis of the known inclinometric transducers and systems shows that the most used inclinometric systems as components of orientation systems are bottomhole inclinometric systems STE, STT of Kharkiv SKBE (presented in 2001 by G. N. Kovshov), which have low accuracy and reliability of measurement.

Inclinometric systems based on ZIS-4 have acceptable accuracy; however, they have large overall dimensions and are limited in their area of use (presented in 2001 by G. N. Kovshov Instruments for control of spatial orientation of wells during drilling). Inclinometer transducers with cable communication channel are currently the most promising, although work continues to improve components of orientation control sensors with electromagnetic communication channel, as well as telesystems with hydraulic communication channel are being developed.

There has also been a great deal of attention overseas to the design, manufacture and operation of inclinometer instrumentation. The main focus has been on the development of downhole systems using ferroprobe and accelerometer sensors operating with cable, hydraulic and electromagnetic communication channels.

The best known foreign companies for the production of CSOCS components are: Sperry-Sun (UK), Robertson Geologing LTD (UK), Azinbee (France), Geoservices (France), Lentern (Germany), Gyrodate Inc. (USA), Gearhart Owen (USA), Schlumberger Anadrill (USA), as well as developers of inclinometer equipment: French Oil Institute Institut Francais du Petrole (IFR), Seeker (Germany), OYO (Japan), CNPC (China), etc.

Summarising the data presented, we can conclude that domestic and foreign researchers and developers pay special attention to improving CSOCS components and information transmission channels.

Selecting and justifying the type of inclinometer transducer that satisfies the requirements of the information and control system is an important aspect that determines the design, construction and operational efficiency of the CSOCS. In the general case of the CSOCS, drilling facilities (presented in 2018 Zhivtsova L.I. Models and Methods of Improvement of Computer Control Systems Components of Spatial Object Orientation Parameters), can be represented in the form of a structural scheme, Fig. 1.

The CIMS is structured with a dynamic part and a stationary part. The information between them is transmitted via a communication channel.

The dynamic part of the CSOCS Drilling Facilities consists of drilling tools, drilling tool control unit; telemetry unit, conversion unit.

Projections of free fall acceleration, the Earth's magnetic field measured by the zenith angle, deflector angle and azimuth transducers are transmitted via a communication link to the stationary part. The stationary part consists of telemetry unit, control unit, operator unit, spatial orientation estimation and control unit.

Angular parameters control of spatial wellbore orientation is carried out by the spatial orientation estimation and control unit, which includes a decoding unit and a computer where the

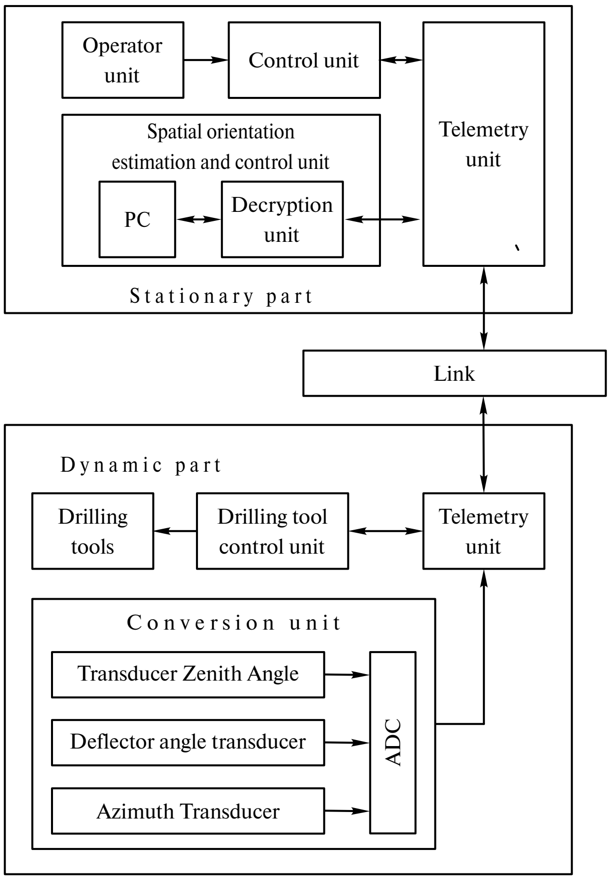

Fig. 1. Structure diagram of a computerised spatial orientation control system (CSOCS) for drilling facilities

results of measurements (zenith angle θ, sighting angle φ and azimuth angle α) are displayed, recorded, processed and stored.

Geophysical measurement technology includes one-off measurements, inclinometry measurements during drilling and final logging. One-off measurements and final logging are carried out by geophysical crews and, in addition to measuring angular parameters, include control of a whole set of geophysical parameters. Inclinometer measurements during drilling are carried out by the drilling team and refer to the operation of an inclinometer as part of the CSOCS.

Based on these data, the current position of the drilling tool is calculated and compared with the design values of the borehole trajectory. The parameters are calculated taking into account external and internal destabilising factors. The results of borehole curvature during boring are monitored with inclinometer transducers. Among the orientation transducers promising are continuous ITs and self-contained drop-type ITs or transporting on a cable.

To solve the technical problem of improving the efficiency of CSOCS, it is proposed to use vibration-resistant inclinometric transducer designs based on three two-stage float-type sensors of the zenith and sighting angles (presented in 2012, G. N. Kovshov, I. V. Ryzhkov, L. I. Zhivtsova, Utility Model Patent of Ukraine, Sensor of zenith and sight angles, No. u201206932).

The transducer, Fig. 2, consists of a sealed cylindrical body *1* in which a sensing element made in the form of a float *2* is placed in the liquid. The float is balanced in the liquid in terms of buoyancy and trim, and in terms of buoyancy – to a certain value. The centre of float weight is displaced relative to xx axis by eccentric weight *3*. In the centre of the float there are fixed axes *4, 5*, which are included in through holes – bushings *6, 7*, which allow angular float rotation around axis xx as well as linear displacement of the float along the axis by 0.5 mm.

A small damping gap of 0.1–0.2 mm is provided between float *2* and transducer body *1*.

The rotation angle of the float around the xx axis is measured by a sine-cosine rotary transformer (SCRT) with the rotor *8* fixed in the float and the stator *9* in the casing. The power supply to the SCRT is provided by a rotary transformer *10*. The transducer housing contains non-contact linear motion sensors *11, 12* and force sensors *13, 14*, with an amplifier *15* and a feedback resistor *16*.

The two-stage float transmitter for the zenith and sighting angles works as follows.

Let the transducer be positioned in the horizontal plane. If the body *1* is tilted away from the horizon, an eccentric weight *3* will cause the float *2* to rotate around the xx axis.

An electrical signal proportional to the angle of rotation of

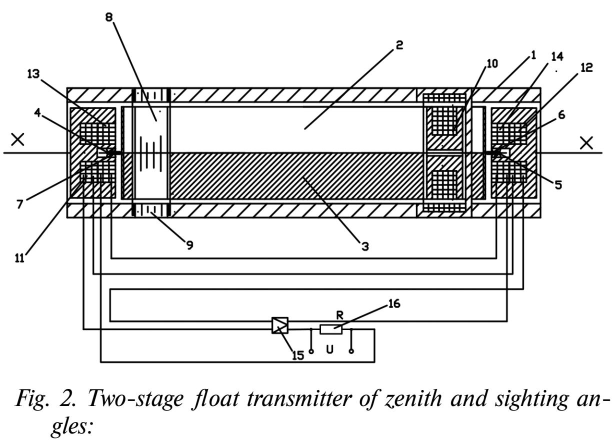

Fig. 2. Two-stage float transmitter of zenith and sighting angles:

1 – body; 2 – float; 3 – eccentric weight; 4, 5 – axes; 6, 7 – bushings; 8 – SCRT rotor; 9 – SCRT stator; 10 – rotary transformer; 11, 12 – linear displacement sensors; 13, 14 – force sensors; 15 – amplifier; 16 – feedback resistor

the float around the xx axis, equal to the setting angle of the deflector, is taken from the stator *9* of the electrical transducer.

The float *2* is moved along the XX axis by an eccentric weight *3*, which shifts the float balanced in the buoyancy fluid to a certain value, allowing linear displacement of the float along the XX axis.

The output of the non-contact displacement sensors *11, 12* is an electrical signal which, after amplification *15* and conversion, is fed to the windings of the non-contact force sensors *13, 14*, which return the float to its home position.

The output signal of an inclinometric transducer based on three two-stage float transmitters for the zenith and sighting angles U_i is as follows

$$\begin{cases} U_1 = U_{01} + U_{m1} \cdot b_1 \\ U_2 = U_{02} + U_{m2} \cdot b_2 \\ U_3 = U_{03} + U_{m3} \cdot b_3 \\ U_1^* = U_{01}^* + U_{m1}^* \cdot b_1^* \\ U_2^* = U_{02}^* + U_{m2}^* \cdot b_2^* \\ U_3^* = U_{03}^* + U_{m3}^* \cdot b_3^* \end{cases}, \quad (1)$$

where U_{01}, U_{02}, $U_{03}$are zero signals from primary angle transducers independent of vector position $\bar{g}$; $U_{01}^*, U_{02}^*, U_{03}^*$ are zero signals from the primary transducers; U_{m1}, U_{m2}, U_{m3} are the highest values of the output signals from the primary angle transmitters; $U_{m1}^*, U_{m2}^*, U_{m3}^*$ are the highest values of the output signals from the primary transducers; b_1, b_2, b_3 are directional cosines between the $\bar{g}$ vector and the axes of sensitivity of the primary angle transducers; b_1^*, b_2^*, b_3^* are directional cosines between $\bar{g}$ vector and primary transducer sensitivity axes; $\bar{g}$ is the vector of gravity acceleration on the sensitivity axis of the i^{th} primary transducer, where

$$\begin{cases} b_1 = -\cos\phi \cdot \sin\theta \\ b_2 = \sin\phi \cdot \sin\theta \\ b_3 = \cos\theta \\ b_1^* = -\dfrac{\Delta m_1 \cdot \cos\phi \cdot \sin\theta}{C_1} \\ b_2^* = \dfrac{\Delta m_2 \cdot \sin\phi \cdot \sin\theta}{C_2} \\ b_3^* = \dfrac{\Delta m_3 \cdot \cos\theta}{C_3} \end{cases},$$

where $\Delta m_i = m - m_i$, $i = 1, 2, 3$; m_i is liquid connected to the float mass; m is float weight; C_i is "electrical" feedback spring stiffness.

However, the inclinometer, which is an integral part of a drill pipe, performs lowering and raising on a cable, throwing into a borehole, lowering and raising together with a drilling tool, is installed in the drill pipe with a certain margin of error. This is due to the fact that the mounting surfaces of transducers and corresponding seating surfaces in inclinometer are made with a certain technological tolerance. Accordingly, the sensitivity axes of the primary transducers do not coincide with the geometrical axes formed by the mounting surfaces of the inclinometer.

In addition, the individual electrical parameters of transducers, even from the same batch, differ from each other. Failure to account for these parameters (instrumental errors) leads to significant measurement errors, which reduces the efficiency of CSOCS.

To improve accuracy in determining the spatial orientation of drill targets, the influence of the factors listed above must be taken into account in (1).

The IT output signal of the three two-stage float transmitters for the zenith and sighting angles, taking into account the instrumental errors, is as follows

$$\begin{cases} U_1 = U_{01} + U_{m1} \cdot (-\cos\phi \cdot \sin\theta - \varepsilon_{21} \cdot \cos\theta + \varepsilon_{31} \cdot \sin\phi \cdot \sin\theta) \\ U_2 = U_{02} + U_{m2} \cdot (\sin\phi \cdot \sin\theta + \varepsilon_{32} \cdot \cos\phi \cdot \sin\theta + \varepsilon_{12} \cdot \cos\theta) \\ U_3 = U_{03} + U_{m3} \cdot (\cos\theta - \varepsilon_{23} \cdot \cos\phi \cdot \sin\theta - \varepsilon_{13} \cdot \sin\phi \cdot \sin\theta) \\ U_1^* = U_{01}^* + U_{m1}^* \cdot \left(-\cos\phi \cdot \sin\theta \cdot \frac{\Delta m_1}{C_1} + \varepsilon_{21}^* \cdot \cos\theta \cdot \frac{\Delta m_3}{C_3} - \varepsilon_{31}^* \cdot \sin\phi \cdot \sin\theta \cdot \frac{\Delta m_2}{C_2} \right) \\ U_2^* = U_{02}^* + U_{m2}^* \cdot \left(\sin\phi \cdot \sin\theta \cdot \frac{\Delta m_2}{C_2} + \varepsilon_{32}^* \cdot \cos\phi \cdot \sin\theta \cdot \frac{\Delta m_1}{C_1} + \varepsilon_{12}^* \cdot \cos\theta \cdot \frac{\Delta m_3}{C_3} \right) \\ U_3^* = U_{03}^* + U_{m3}^* \cdot \left(\cos\theta \cdot \frac{\Delta m_3}{C_3} - \varepsilon_{23}^* \cdot \cos\phi \cdot \sin\theta \cdot \frac{\Delta m_1}{C_1} - \varepsilon_{13}^* \cdot \sin\phi \cdot \sin\theta \cdot \frac{\Delta m_2}{C_2} \right) \end{cases}, \quad (2)$$

where $\tilde{\varepsilon}_1, \tilde{\varepsilon}_2, \tilde{\varepsilon}_3$, $\tilde{\varepsilon}_1^*, \tilde{\varepsilon}_2^*, \tilde{\varepsilon}_3^*$ are sensing axes angular deviations of the three two-step float probes, relative to the measuring axes of their mounting surfaces in the inclinometer; U_{0i}, U_{mi}, U_{0i}^*, U_{mi}^* are converters' individual electrical parameters.

The transmission of information from the borehole, which is about 3000 m deep, is carried out under both difficult operating and interference conditions.

In order to comprehensively improve the efficiency of CSOCS and drilling control and to increase the reliability of the system it is necessary to have devices in the stationary part of signal reception capable of operating in complex interference-signal conditions. Then the frequency-dependent components (FDC) of the signal receiving path in the software and hardware must be easily controlled for tuning the main characteristics, which will improve the accuracy of information signal extraction from the sensor.

Top-level modulated signal reception requires bandpass-type FDC with the possibility of tuning the fundamental frequency and reception bandwidth. It is difficult to control such high-order components because many coefficients are interrelated [9], so in most cases, different connections from low-order FDCs are used in controlling the characteristics [10], for example, by connecting low-order FDCs of the same type in series. This improves controllability and reliability and makes component rearrangement easier and simpler [11]. Known FDCs have limitations which are related to the complexity of controlling the characteristics during their tuning [12].

To improve the system quality, it is proposed to consider low-order tunable bandpass FDCs. Their use in the information and control system can reduce the computational cost and time for calculating new values when tuning the characteristics, as well as by cascading the same-type FDCs to increase the order of the processing path and simplify control [13, 14].

However, the existing methods for reconfiguring bandpass FDCs have a number of drawbacks [15, 16]. One of the main ones is the computational cost of the calculation [17, 18].

It is proposed to find simpler ratios for low-order bandpass FDCs. This will speed up the calculation process considerably.

As low-order frequency-dependent bandpass components (LO BFDCs), let us consider the commonly used generic transfer functions of a general form

$$H(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2}}{1 + b_1 z^{-1} + b_2 z^{-2}}, \quad (3)$$

where a_0, a_1, a_2, b_1, b_2 are the numerator and denominator real coefficients.

In this case, the bandpass FDCs corresponds to the transfer function (3), provided that the numerator coefficients $a_0 = -a_2$ and $a_1 = 0$ [9].

By converting according to the Euler formula

$$z^{-1} = \cos(\varpi) - \varphi \sin(\varpi),$$

where ϖ is normalized angular frequency; $\varpi = 2\pi \frac{f}{f_d}$, $\varpi \in [0, \pi]$; f, f_d are linear frequency and sampling frequency, respectively, we obtain the complex gain and, based on this, the amplitude-frequency response (AFR) and the phase-frequency response (PFR) of the frequency-dependent bandpass components, Fig. 3:

- AFR

$$H(\varpi) = \sqrt{\frac{(2a_0 \sin(\varpi))^2}{(1-b_2)^2 + b_1^2 + 2b_1(1+b_2)\cos(\varpi) + 4b_2}}; \quad (4)$$

- PFR

$$\phi(\varpi) = arctg\left(\frac{b_1 + (1+b_2)\cos(\omega)}{(1-b_2)\sin(\varpi)} \right). \quad (5)$$

To improve controllability when tuning the AFR, it is necessary to determine the effect of changing the transfer function coefficients a_0, b_1, b_2 on the amplitude and cut-off frequency of the AFR.

The bandwidth of the BFDC is defined as

$$\Delta\varpi = \varpi_2 - \varpi_1,$$

and the bandwidth centre frequency is

$$\varpi_0 = \varpi_1 + \frac{\Delta\varpi}{2} = \varpi_1 + \frac{\varpi_2 - \varpi_1}{2}.$$

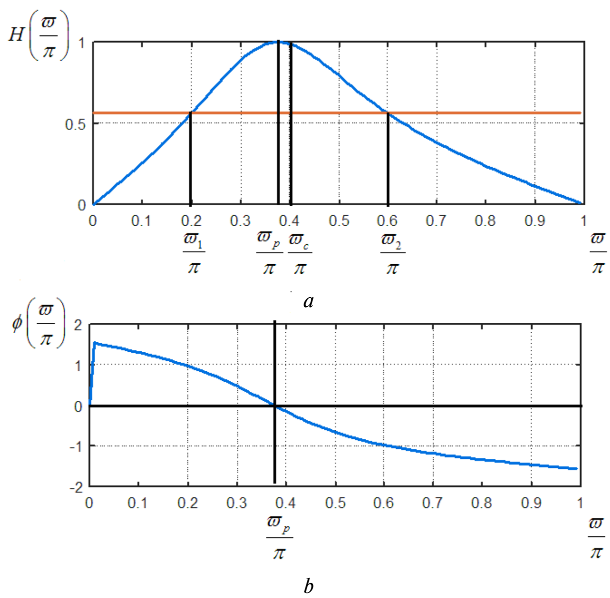

Fig. 3. AFR and PFR of a generalised normalised digital bandpass filter at oscillation RP = 5 and cut-off frequencies:

$a - \frac{\varpi_1}{\pi} = 0.3$; $b - \frac{\varpi_2}{\pi} = 0.7$

From the AFR and PFR analysis, it follows that at the AFR peak frequency, the phase-frequency response is zero, Fig. 3. This made it possible to determine this frequency from the PFR (3). By equating the numerator of the PFR to zero

$$b_1 + (1 + b_2)\cos(\varpi_p) = 0.$$

Get the following

$$\cos(\varpi_p) = -\frac{b_1}{(1+b_2)}. \quad (6)$$

On the other hand, by determining the derivative of the AFR and equating it to zero, you can also find the cosine of the peak frequency

$$\cos(\varpi_p) = -\frac{b_1(1+b_2)}{4(a_0^2+b_2)}. \quad (7)$$

The following observation can be made from the analysis of the AFR and PFR of the frequency-dependent components. The peak frequency ϖ_p of the AFR does not always coincide with the mid-bandwidth ϖ_0, as shown in Fig. 1. Quite often they do not coincide, e. g. Fig. 4.

Fig. 4 shows that the peak frequency $\frac{\varpi_p}{\pi} = 0.39$, the passband centre $\frac{\varpi_c}{\pi}$ is 0.4.

Equating (6, 7), we obtain equations of the form

$$(1+b_2)^2 = 4(a_0^2 + b_2).$$

By solving this equation, we obtain the dependence of the numerator coefficient a_0 on the denominator coefficient b_2

$$a_0 = \frac{1-b_2}{2}. \quad (8)$$

Thus, the AFR amplitude is determined by the denominator factor b_2.

Consider the denominator coefficients b_1 and b_2 effect on the AFR properties.

The cut-off frequencies ϖ_1 and ϖ_2 are defined at level c, which is given by the ripple ratio in the passband ε. For example, for a Butterworth filter, c is specified at 0.707.

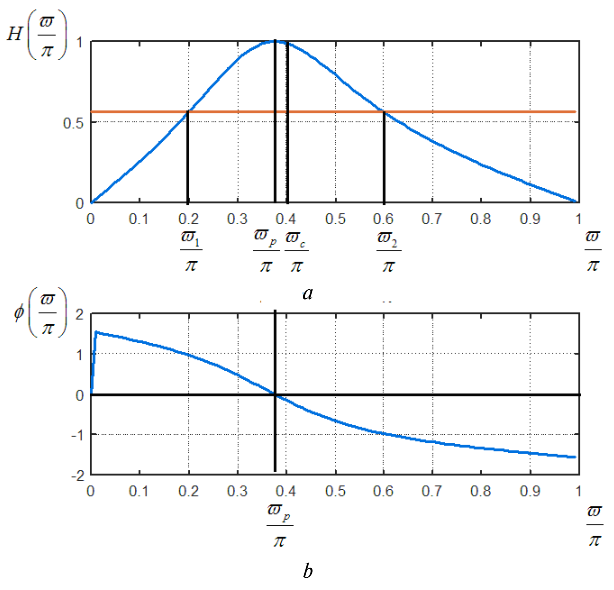

Fig. 4. AFR and PFR of a generalised normalised digital band-pass filter at oscillation RP = 5 and cut-off frequencies:

$a - \frac{\varpi_1}{\pi} = 0.2$; $b - \frac{\varpi_2}{\pi} = 0.6$

It should be noted that in most mathematical packages, the ripple level is specified in decibels:

RP – passband oscillation;

RS – stopband oscillation.

However, in both cases

$$c = \frac{1}{\sqrt{10^{0.1RP}}};$$

$$c = \frac{1}{\sqrt{10^{0.1RS}}}.$$

For Butterworth digital filters, the RP value is – 3 dB, with a c – value in the range $0 < c < 1$.

Then for the AFR square, two equations can be generalised for each cut-off frequency

$$\begin{cases} \dfrac{(2a_0\sin(\varpi_1))^2}{(1-b_2)^2 + b_1^2 + 2b_1(1+b_2)\cos(\varpi_1) + 4b_2} = \dfrac{1}{2} \\ \dfrac{(2a_0\sin(\varpi_2))^2}{(1-b_2)^2 + b_1^2 + 2b_1(1+b_2)\cos(\varpi_2) + 4b_2} = \dfrac{1}{2} \end{cases}. \quad (9)$$

From the first equation, express the denominator coefficient b_1 by substituting from (8) the value of the numerator coefficient a_0.

Solving this equation, we obtain the following solution

$$b_1 = -(1 + b_2)\cos(\varpi_1) \pm (1 - b_2)\sin(\varpi_1).$$

The relationship analysis revealed that the coefficient b_1 for the cut-off frequencies ϖ_1 is determined as follows

$$b_1 = -(1 + b_2)\cos(\varpi_1) + (1 - b_2)\sin(\varpi_1), \quad (10)$$

and for the cut-off frequency ϖ_2 it is as follows

$$b_1 = -(1 + b_2)\cos(\varpi_2) + (1 - b_2)\sin(\varpi_2).$$

Substituting ratio (10) for the coefficient b_1 into the second equation from (9), we obtain a number of additional ratios, the analysis of which allowed us to determine the value of the denominator coefficient b_2 as

$$b_2 = \frac{\cos(\varpi_1) + \sin(\varpi_2)}{\cos(\varpi_2) - \sin(\varpi_1)}.$$

The results were verified by experiment. Under laboratory conditions, tunable low-order FDCs were introduced into the software of the computer information and control system instead of the old FDCs.

The implementation of such a FDC based on a canonical structure with ordered node weights allowed developing a system of equations to write a program that implemented this FDC.

$$\begin{cases} x_1(n) = s(n) \\ x_2(n) = x_3(n-1) \\ x_3(n) = x_4(n-1) \\ x_4(n) = x_1(n) - b_2x_2(n) - b_1x_3(n) \\ y(n) = x_5(n) = a_0x_4(n) + a_2x_2(n) \end{cases},$$

where $s(n)$, $x_i(n)$, $y(n)$ are respectively input sequence, state of the i^{th} node of the canonical FDC structure, output sequence of the FDC.

The field experiment showed that in the presence of the old FDC, when the frequency of the input signal drifted, the obtained data had an error, while in the presence of the proposed FDC and operational adjustment the error was levelled, in addition for these FDCs reduction in computational cost was 13 %.

Conclusion. Increasing efficiency of computer information-control system for control of spatial orientation of drilling objects is a topical scientific and technical problem, the complex solution of which provides increase in inclinometric quality works and decrease in prime cost of carrying out technological operations of various purposes.

As a rule, commercially available inclinometer transmitters have poor accuracy and reliability and cannot be used as components of directional control instrumentation for drilling targets.

One of the most promising directions to date has been proposed, which is to research, develop and build ITs based on vibration-resistant float-type transducers.

For the first time, a design of an inclinometer and sighting angle transmitter made in the form of an elongated cylindrical float having two degrees of freedom: movement along the longitudinal axis and rotational movement around the axis of symmetry are proposed. The advantages of the inclinometer transmitter include: reliability, simplicity of design, and the ability to operate while drilling.

Taking into account operating conditions of inclinometer transducers in the process of drilling, an error of measurement of suggested vibration-proof two-stage float transducer of zenith and sighting angles does not exceed 0.3° when measuring the zenith angle (the angle of deviation from vertical) and 3° when measuring the angle of diverter installation.

The use of modern computer technology in Industry 4.0 makes it possible to contribute to increasing the efficiency of such systems by reducing the computational costs and calculation time for performance tuning.

The AFRs analysis of the considered generalized bandpass FDCs shows that the values of numerator a_0 and denominator b_1 and b_2 coefficients can be found unambiguously, depending on the given cutoff frequencies and taking into account the level of ripple in the passband, when developing bandpass digital FDCs. Simpler formulas to calculate the necessary coefficients of the transfer function of the frequency hopping filter are obtained.

Rearranging the characteristics of the FDC, based on the resulting formulas, allows a reduction in computational cost of 13 % and a rapid change, leading to an increase in the efficiency of the system as a whole.

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Комплексне підвищення ефективності комп'ютерної системи контролю параметрів просторової орієнтації бурових об'єктів

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Мета. Підвищення ефективності системи за рахунок підвищення точності при визначенні просторової орієнтації бурових об'єктів, а також підстроювання компонент системи для більш точного виділення інформаційного сигналу від перетворювача кутів.

Методика. Комплексне підвищення точності перетворювача кутів засноване на врахуванні впливу факторів і похибок при визначенні просторової орієнтації бурового об'єкта, а також можливості плавної перебудови характеристик приймальної частини за рахунок відходу частоти інформаційного модульованого сигналу від перетворювача кутів.

Результати. Ураховуючи умови експлуатації інклінометричних перетворювачів у процесі буріння, похибка вимірювання запропонованого вібростійкого двоступеневого поплавкового перетворювача зенітного й візирного кутів не перевищує 0,3° при вимірюванні зенітного кута (кута відхилення від вертикалі) та 3° при вимірюванні кута установки відхилювача. Крім того, перебудова характеристик частотно-залежних компонент приймальної частини системи дозволяє оперативно внести зміни й підвищити точність виділення інформаційного сигналу

від перетворювача, що підвищить ефективність функціонування системи в цілому.

Наукова новизна. Комплексне вирішення завдання підвищення ефективності системи контролю полягає в підвищенні точнісних показників перетворювача, за рахунок урахування його похибок у процесі експлуатації, а також підвищення плавності та оперативності перебудови характеристик приймальної частини, за рахунок можливості обчислення коефіцієнтів передавальної функції за спрощеними співвідношенням, що значно спростить процес обробки інформації та підвищить якість інклінометричних робіт.

Практична значимість. Дане комплексне рішення, доведене до конструкції, виготовлення та експериментальної перевірки перетворювача, а також запропоновані й доведені до реалізації алгоритми та програми перебудови частотно-залежних компонент.

Ключові слова: *інклінометрічні датчики, смуговий фільтр, частота піку, амплітудно-частотна характеристика, фазочастотна характеристика, коефіцієнти передавальної функції*

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