Motion Model of Vibrational Source of Azimuth Correction System of an Inclinometer

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***Abstract*— Paper contains description of system of azimuthal correction of an inclinometer – alternative system for determination of azimuthal position on the Earth in general and in high latitude areas particularly. Moreover description of basic functional units of the system is presented, considered design of vibrational source unit and seismic receiver unit. Also in paper way to develop a model of vibrational source and to examine a motion of vibrational source are disclosed. In accordance with model of vibrational source a modelling of operation of the source was conducted, results of modelling and comparison with experimental data are given.**

***Keywords*— azimuthal correction; borehole; inclinometer; accelerometer; vibrational source;, simulation; model**

I. Statement of Problem

In evolution of methods of cluster drilling a problem of exact positioning of bottomhole drilling string arrangement in the Earth crust has come to the fore. Inclinometers with magnetic sensors, inertial angular velocity sensors and acceleration sensors are used to determine the azimuthal angle, zenith angle and tool face angle of wells. In basis of their signals actual position of the bottom drill string in the Earth crust is calculated. The navigation systems obtained by this way have a number of limitations connected with principles of operation of sensors and the measurements that are being carried out. For example, when drilling wells are developed in high latitude areas - more than 60^{o}, the efficiency of azimuthal sensors (gyroscopes and magnetometers) decreases due to decreasing of horizontal component of the Earth's rotation velocity and decreasing of horizontal component of the Earth's magnetic field correspondingly. This issue leads to significant errors in estimation and calculations of azimuthal position. If we take into account that at high latitude areas in order to reduce financial costs for installing drilling platforms the methods of cluster drilling are most commonly used and a number of wells from one wellhead is much higher than in the small and medium latitudes up to 60^{o}, so the low accuracy of locating of bottom drilling string significantly increases the probability of convergence of boreholes and possible damage for adjacent well bores and can lead to terrible accidents. From this point of view for drilling in high latitude areas there is a heightened interest in methods for accurate determining of position of drilling assembly in crust.

Firstly a method of azimuth correction of an inclinometer based on measurement of small harmonic vibrations of the Earth's crust when vibration from source of vibrational disturbances is propagated to receiver. And secondly in detail dynamic system of the vibrational source, it model and it motion modelling are proposed for consideration.

II. Method of Azimuth Correction System of an Inclinometer

The method of azimuth correction of the inclinometer as noted above is based on measuring of small vibrational (seismic) responses of the Earth's crust in response to vibrational disturbance and on calculating of mutual azimuthal position of sources of disturbances and receivers [1]. To implement the method of azimuthal correction it is proposed to use a scheme where vibrational sources of vibration disturbance are located at points at a known distance from wellhead in direction to project drilling. To measure small responses of the Earth's crust it is proposed to use as seismic receivers accelerometers of the inclinometer.

In Fig. 1. scheme of the azimuth correction system of the inclinometer is shown .

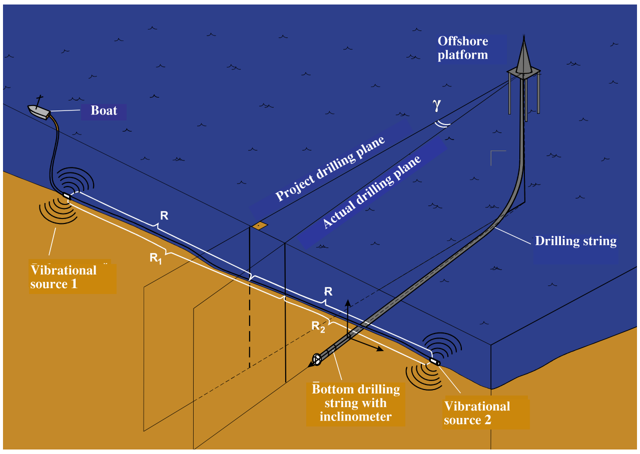

Fig. 1. Scheme of azimuth correction system of an inclinometer

Drilling of the well is performed from the offshore drilling platform in project direction by methods of directional and horizontal wells wiring. In bottom drill string an inclinometer with accelerometers is installed and they act as receivers of the

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azimuth correction system. At known distance from the wellhead perpendicularly to project drill direction and at the same distances R from the project drilling plane there are sources of vibrational disturbances. Vibrational sources are installed in a plastic pipe and laid on sea bottom by a ship. During periods of drilling stops, power is supplied to the vibrational sources, excitation of oscillations in the Earth's crust and measurement of parameters of small vibrational oscillations passing through Earth's crust to accelerometers of the inclinometer from sources of disturbance. Calculation of the direction of the actual drilling plane and its deviation from the project drilling plane are made by values of distances R1 and R2 between the inclinometer and two vibrational sources. For calculation of distances both the calculation of time delay of signal propagation can be used when it passing through crust from sources to the receiver in analogy with global positioning systems (GPS) and calculation of a degree of attenuation of seismic signal as the oscillations pass through the Earth's crust

Advantages of this arrangement of the azimuth correction system are follows. Firstly, it is the possibility to use accelerometers [3] of the inclinometer as receivers of small vibrations of the Earth's crust. Such accelerometers are stable for large shock accelerations and vibration [4, 5, 6] and wherein they alloy to measure small seismic vibrations passing through crust. Secondly, in this arrangement there is the possibility to exclude an influence of noise from the operation of the Earth's surface equipment on the readings of accelerometers. Another feature of this scheme is the refusal to use the downhole motor of the well as a source of vibration perturbations of crust. It should be noted that a downhole motor generates significant vibration disturbances over a wide frequency range, however they make difficulties to isolate the main carrier frequency of the vibration signal and therefore significantly increase noise in the measurements. By this it is proposed to use own vibration sources in the azimuth correction system.

III. VIBRATIONAL SOURCE OF SEISMIC DISTURBANCES

To create a disturbance which is discernible at a considerable distance and to conduct qualitative measurements it is necessary to use a powerful source of vibration disturbance. As source it is proposed to use a flexible shaft driven by motor [7]. When power is applied to the motor the shaft starts to rotate, the amplitude of the oscillations increases. To obtain the maximum amplitude of the oscillations it is proposed to choose a rotational speed close to resonant but not exceeding it. To ensure a small attenuation of oscillations in the Earth's crust the vibrational frequency should be chosen sufficiently low – 10-20 Hz.

The design of the vibrational source is shown in Fig. 2.

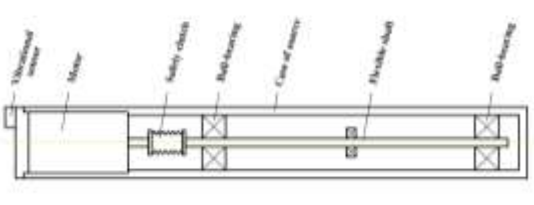

Fig. 2. Design of vibrational source with flexible shaft

When the drilling stopped power is supplying to the sources, oscillations are generating for a time within ~1 minute and vibrational amplitudes are measuring and maintaining the same for both sources. Thus the required vibrational premise is creating and then subsequently recording by the accelerometers of the inclinometer.

By accelerometers readings a spectrum range of vibrational accelerations acting in the bottom drilling string during drill stops is generated. By amplitude of the spectrum a decision about correspondence of actual drilling plane to project drilling plane is made and the correction of drilling direction is proposed.

IV. MODEL OF VIBRATIONAL SOURCE

To understand the physical processes in shaft during his rotation and also to determine controlling mode of motor of the source of vibrational disturbances to generate the vibrational premise a modelling of operation of source with flexible shaft was performed.

The computational model is shown in Fig. 3. For calculations the shaft is presented in form of a point mass *m* displaced relatively to axis of rotation to distance *e*, the point A is fixed elastically with rigidity *k* to axis of rotation and might slide along the weightless guide OA. The torque is transmitted to the shaft from the motor through an elastic safety coupling (Fig. 2), bending stiffness of the coupling in these calculations is neglected. Bearings are absolutely rigid and allow only rotation around the axis passing through point O perpendicularly to figure plane.

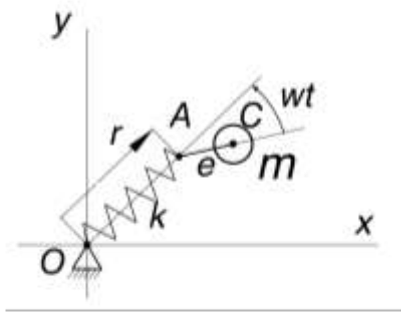

Fig. 3. Model of flexible shaft

Modelling is performed on basis of [8] and [9]. According to [8] equations of motion of a mass will have the form:

$$I_x \ddot{x} + D_x \dot{x} + k_x x = me\omega^2 \cos \omega t$$
$$I_y \ddot{y} + D_y \dot{y} + k_y y = me\omega^2 \sin \omega t$$
$$I_z \dot{\omega} = M_{motor}$$

Initial conditions are follow:

$$x = \dot{x} = y = \dot{y} = 0,\ \omega = 0;$$

Parameters of the system are:

$$m = 0.8\ kg;\ r = 0{,}005\ m;\ e = 0.001\ m;\ M_{motor} = 300\ Nsm$$

The solution of equations is realized by numerical integration of a system of eight ordinary differential equations of the first order by means of the function ode45 in the Matlab software package.

A graphical representation of solution of the system of differential equations is shown in Fig.4. Figure Fig. 4a show that the acceleration of the shaft is carried out to a certain limited angular velocity. Acceleration can be carried out gradually by slowly increasing a torque of the motor. It is also possible that the torque from the motor corresponds to the nominal full torque and is immediately fully transmitted to the shaft performing its "rapid" acceleration. The analysis of processes during start of electric machines [9] shows that the peak value of rotation resistance moment corresponds to the resonance frequency of rotation under a slow increasing of angular velocity of the rotating shaft. It can be explained by maximal amplitude of shaft oscillations according to the amplitude-frequency characteristic. With an unchanged slow increasing of velocity the system becomes unable to make the transition over resonance rotational velocity. The Sommerfeld effect is observed.

At fast increasing of shaft velocity ("rapid" acceleration), when the resonance passes, the system does not have time to swing to peak value of the amplitude of the oscillations. Therefore, during "rapid" acceleration the shaft overcomes several resonant frequencies, which can be clearly seen from the decay of the oscillation amplitudes in the x and y directions (Figures 4b and 4c).

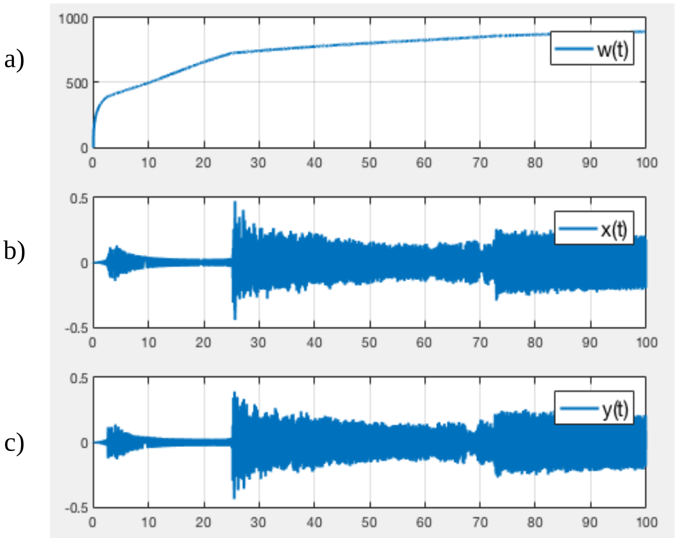

Fig. 4. a) Angular velocity of the shaft; b) and c) coordinates of point mass

According to experiments with flexible shaft and measurements of it oscillations difference between "rapid" and "slow" acceleration also was traced. But an interesting phenomenon of this motion was in a double change in the frequency of oscillations during a transition through resonance under "slow" acceleration. For example, the base frequency of oscillations is ~ 19 Hz and when shaft is passing through resonance it increases to the second frequency of ~ 40 Hz.

It should be noted that this frequency change was observed both in modelling and in experiments with a experimental sample of a vibrational source. However, the oscillation frequency varies by a factor of 2. At "rapid" acceleration of the shaft of the transition from the first form to the second flow, when the resonance speed of rotation was reached, did not occur.

On the basis of the described authors came to the conclusion that in spite of a simple mechanical scheme of the source of vibration perturbation of the Earth's crust with a flexible resonating shaft the study of its work is a complex problem and should be considered in detail additionally, since in this case there is a complex dynamic system with distributed inertial and rigidity parameters. Its analysis is complicated because of changing in time of the mass-inertial characteristics of the flexible shaft due to the change in the shape of its elastic line, as well as ambiguity of options for choosing of control parameters of electric voltage applied to the electric motor that drives the shaft.

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