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Sound vibration modulator to control turbodrill operation

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Abstract: The paper describes a sound vibration modulator to control turbodrill revolutions during turbine motor drilling. The principle of the modulator operation is based on the quarter-wave acoustic resonator property to suppress noises at the resonant frequency. A resonant chamber, which is a quarter-wave acoustic resonator, is embedded into the sound vibration modulator to control the number of turbodrill revolutions. The resonant chamber is a hollow cylinder with two cavities: an internal closed annular cavity and a central cylindrical cavity. During each revolution of the turbodrill shaft absorption of sound energy occurs at a frequency equal to the resonant chamber frequency, i.e. it creates a wave break. The number of these breaks will be equal to the number of turbodrill revolutions.

1. Introduction

Drilling efficiency depends on a group of factors: axial load on the bit, bit rotation frequency, drilling mud circulation rate and parameters of the drilling mud quality, a bit type, geological conditions, mechanical properties of rocks.

They distinguish the drilling practices parameters which can be changed from the driller's panel during the bit operation in the bottom hole, and the factors established at the well construction design stage, some of which cannot be quickly changed. The first ones are called managed ones. Their certain combination, when mechanical well drilling is carried out, is called drilling practices.

During well drilling there is a necessity to monitor the drilling site day-and-night; and, if required, immediately bring in necessary adjustments to the process of well drilling.

The information obtained from the bottomhole telemetering means of control which are under specific, quite hard conditions, takes an important place in the control parameters solution during turbine motor drilling.

For many years, the main obstacle for practical use of measurements in the drilling process was the communication channel. It is the main and decisive factor, as it determines the MVD (measure while drilling) design, arrangement, information content, reliability, convenience of operation, as well as the conditions of passing signals.

The main requirements to the downhole information include increasing the reliability of the measuring signal, which is transmitted to the surface through the drill string and the flow of drilling fluid under conditions of high vibration, pulsation and noises generated by the drilling rig injection pump line.

Therefore, the problem of improving measurement and transmission of operating parameters when drilling wells has always been relevant.

The search for solutions to this problem aims at a development of new technical means for measuring operating parameters and development of a noise-proof communication channel, which is to provide telemetering of downhole parameters with the required accuracy and to be reliable for a long operating time to control drilling parameters.

In the course of turbine motor drilling, two sources of sound occur in the bottomhole: one - from the turbodrill and the other - from the bit. The turbodrill generates the sound into the inner cavity of the pipe; and the bit generates it not only into the drill string, but also into the drilling fluid of the annular space.

2. Research

The currently available range of the communication channels is very wide and represented by hydraulic, electromagnetic, acoustic, electrically conductive and many other types of communication channels.

As a result of long-term research work and practical use in real drilling conditions the following three communication channels are widely used:

- electrically conductive (ECCC);
- hydraulic (HCC);
- electromagnetic (EMCC).

Each of these communication channels has its advantages and disadvantages. The diversity of drilling conditions and economic feasibility designate its field of application for each communication channel.

By today various methods of information transfer have been developed, both in our country and abroad [1], [2], [3], [4]. Some of them are based on the analysis of vibration displacement of the drill string upper part and do not require any use of downhole automation devices.

The analysis of the existing channels of communication with the wellhead has shown that the most promising in terms of reliability and efficiency is the hydraulic communication channel (HCC), with relative simplicity of transmitting and receiving devices, and absence of any additional communication line built in the drilling tool.

MWD with HCC differs from others having a device that creates pressure pulses in the drilling fluid flow which represent information about the drilling practices. Several devices of different type are used to generate pressure pulses in the drilling fluid. The signal generated by them is divided into three types: positive pulse, negative pulse or continuous wave.

Positive pulses are generated by creating a short-term partial overlap of the drilling fluid downflow. Negative pulses are generated by short-term liquid bypasses into the annular space through the side valve. Hydraulic signals, close to harmonic ones, are generated by an electric motor that rotates the pulsator valve. Hydraulic pulses come to the surface through the drilling liquid column at a speed of about 1250 m/s, where the information, encoded in various ways, is decoded and displayed in a form acceptable for the operator.

The preference in use of MWD with HCC is based on both a relative simplicity of communication compared to other communication channels and the fact that this channel does not break down (compared to ECCC) technological operations during drilling and does not depend on the geological cross-section (compared to EMCC). The disadvantages of this communication channel are: the low information content due to the relatively low transmission rate, low noise immunity, consistency in information transmission, requirement of an electric power source (battery, turbo-generator), hydraulic energy outfeed for transmitter and turbo-generator operation and impossibility to work with air blowing and aerated liquids.

In this paper the authors suggest to use the hydraulic communication channel to transmit the acoustic signals that carry information about drilling parameters rather than pressure waves.

The authors of the paper [1] suggest to form a bit vibration noise frequency absorption band by means of an acoustic resonator at the bottomhole in the frequency spectrum of annular space elastic vibrations, and the sound vibration of the drilling unit body should be absorbed by a local vibration absorber. In this case the frequency absorption band corresponds to the downhole information transmission band.

Theoretical and experimental studies of the acoustic communication channel carried out by Dozorova T. A. [5], [6], Mikhailovsky V. N. [7], Shumilovsky N. M. [8] and Yamaliev V. U. [9] allowed to establish a frequency range of sound waves (0 – 10000 Hz) in the well and to estimate the longitudinal waves absorption coefficient in the drill string filled with clay mud (with density of 1.15 g/cm3), which ranges from 4.2 to 5.2 dB/1000 m with an mean value of 4.7 dB/1000 m. The sound level of operating roller cone bits is in the range of 75 – 95 dB and the channel coverage is 5 – 7 km at frequencies of 150 – 200 Hz.

The occurrence of sound waves generated by the drilling tools can be used to transmit information about the operating conditions of the turbine motor drilling.

But the information about drilling parameters is overlapped by interference in the form of noises generated by the bit and drilling pumps.

To suppress the noise generated by the bit a quarter-wave acoustic resonator, the resonant frequency of which is equal to the bit noise frequency, is suggested to be used.

Acoustic resonators can be used to amplify or attenuate a certain range of acoustic frequencies. The most vivid example of the acoustic "amplifier" is the acoustic system phase inverter which is the same Helmholtz resonator excited "from inside". If the Helmholtz resonator is excited from outside, it becomes an elimination (suppressive) filter that absorbs the energy of external vibrations.

3. Results and discussion

One of the new trends in the application of acoustics in the oil industry is the use of technological noises as useful signals and energy sources. As it is known, operation of any equipment is accompanied by noises that are not useful.

Every mechanical elastic system has its own vibration frequency. If any force brings this system out of balance and then ceases to function, the system will oscillate for some time near its equilibrium position. The frequency of these oscillations is called natural oscillation frequency of the system. The rate of its attenuation depends on the elastic properties, mass and friction forces and does not depend on the force that caused the oscillations.

Full resonance occurs at exact coincidence of the force oscillations frequency and the natural oscillations frequency of a structure and equal positive and negative amplitudes. Partial resonance occurs at incomplete coincidence of the frequencies and unequal amplitudes [1].

The analysis of the existing channels of communication with the wellhead has shown that the most promising in terms of reliability and efficiency is the hydraulic communication channel which transmits acoustic signals and has relative simplicity of transmitting and receiving devices, absence of any additional communication line built in the drilling tool.

4 ways of obtaining information have been developed as sources of information about the turbodrill shaft revolution frequency:

- a formation of a zone of noise suppression with shock pulses and radiation of elastic vibrations between the shock pulses [10];
- a formation of a wave break with acoustic elimination filter (resonator) [11];
- a formation of wave breaks by pressing the damper to the drill string [12];
- modulation of the drilling tool noise with a rotating body. During the turbodrill shaft revolution a change of a sound wave direction occurs, resulting in a reflection of sound energy with a wave break formation [13].

An acoustic filter is an acoustic resonator made in a form of a vessel open to the external environment through a small hole or a tube. A characteristic feature is an ability to perform low-frequency self-oscillations, the wavelength of which is much longer than the size of the resonator. According to the Helmholtz and Rayleigh theory, an acoustic resonator is regarded as an oscillation system with one degree of freedom.

The natural frequency of an acoustic resonator does not depend on the shape of the vessel and the cross-sectional shape of the pipe and is expressed by the formula [14]:

$$f = \frac{c}{2\pi}\sqrt{\frac{F}{Vh}},$$

where: c is a sound velocity in a medium (drilling mud), m/s;
V is a resonator volume, m^3;
F and h are a cross-section square, m^2 and a pipe length, m.

The quarter-wave resonator is a lateral branch line of the tubular cross-section with a closed end. At the frequency when a quarter of the muffled sound wavelength fits the length of the pipe, the sound wave, getting into the branch line, is reflected from the closed end back into the pipeline, but with the opposite phase in relation to the incident wave. The interference of the two waves of the same frequency, but opposite by phase causes an attenuation of the oscillating process. The resonant frequency at which maximum efficiency of the adjusted pipe occurs is determined by the ratio:

$$f = \frac{c}{4l}(2n+1)$$

where: f is resonant frequency, Hz;
c is sound velocity in a medium (drilling liquid), m/s;
n is the positive integers;
l is resonator length, m;

A property of the acoustic resonator, i.e. reflection and absorption of energy with given frequency from a sound vibration spectrum can be used:

- to reduce a noise, if the noise frequency is in the frequency range of the information signal, thereby to increase the signal/noise relationship; e.g. using acoustic resonator for absorbing the drill pump noise in an injection line;
- to control the turbodrill shaft revolution rate by setting the resonator in the internal cavity of a drill pipe.

The efficiency of the resonator operation is based on the phenomenon of a resonant interaction of chambers having a wave nature and associated with a formation of secondary waves in the resonators connecting pipes after the primary wave travel to the second reflection chamber, return to the first chamber and the secondary reflection from it. If the secondary and subsequent waves are added to the primary wave in phase there is a noticeable strengthening of the latter, and the efficiency of sound absorption decreases. An addition in antiphase leads to an increase in efficiency of the composite resonator.

The development of a sound vibration modulator to control turbodrill revolutions can be given as an example of use of an acoustic resonator [15], [16], [17].

Figure 1 shows a basic diagram of a sound vibration modulator to control turbodrill revolutions; Figure 2 shows a spectrogram of drill string vibrations.

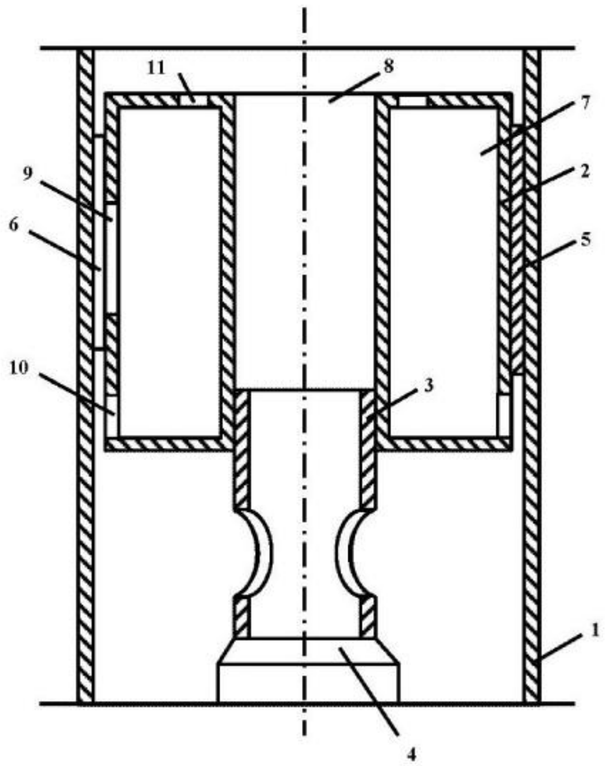

Figure 1. Sound vibration modulator.

A sound vibration modulator to control turbodrill operation comprises a casing-sub (1), a resonant chamber (2), a perforated pipe (3) associated with the turbodrill shaft (4), a bush (5) with a through longitudinal groove (6) installed between the casing-sub (1) and resonant chamber (2). The resonant chamber is made in the form of a hollow cylinder with two cavities: an internal closed annular cavity (7) and a central cylindrical cavity (8). On the outside of the cylinder there is a slotted perforation (9) and flow-through outlet holes (10). The flow-through inlet holes (11) are on the upper end face of the resonance chamber. The central cylindrical cavity is connected to the upper part of the perforated pipe.

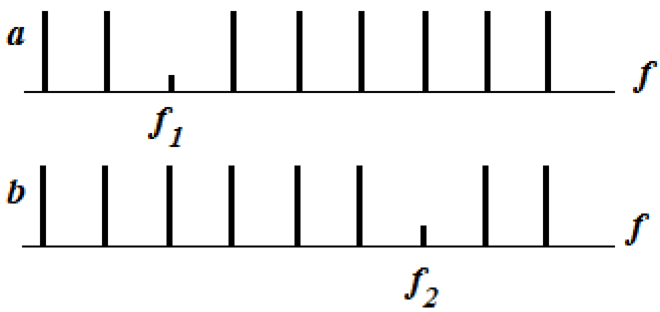

Figure 2. Spectrogram of drill string vibrations.

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The sound vibration modulator to control turbodrill revolutions operates as follows:

Drilling fluid under pressure is supplied into the turbodrill through the central cylindrical cavity (8) and at the same time into the flow-through inlet holes (11) and then to the flow-through outlet holes (10).

When revolving the turbodrill shaft (4) rotates the perforated pipe (3) and reactive resonant chamber (2). With each shaft revolution the slotted perforation (9) is aligned with the through longitudinal groove (6) and the bush (5). In this case absorption of sound energy occurs at a frequency of f_2 (Figure 1) equal to the resonant chamber frequency from the drill string polyharmonic vibrations spectrum. When slotted perforation is blocked by the bush energy absorption via the flow-through inlet and outlet holes occurs and the spectrogram shows absorption of frequency f_1. Maintenance of constant internal volume of the closed annular cavity (7) is provided due to self-cleaning from sludge particles. Solid particles settled down on the bottom of the chamber (2) are removed by the drilling fluid under the centrifugal force flowing through the outlet holes.

4. Conclusion

The proposed sound vibration modulator to control the turbodrill revolutions does not require electrical energy because it uses the noise energy occurring in the process of well drilling. The simplicity of transmitting and receiving devices, and absence of any additional communication line built in the drilling tool provides increased reliability and performance of the hydraulic communication channel used to transmit acoustic impulses. In this regard, we can conclude that the way to control the number of turbodrill revolutions is safe. The absence of tuning and adjusting devices in the proposed modulator design provides an ease of operation and does not require high qualification.

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