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WIRELESS DATA TRANSFER CHANNEL IN THE MONITORING SYSTEMS OF OIL PRODUCTION WELLS

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The article examines a possible option of organizing an acoustic transfer channel of metrological data, wherein tubing of oil production wells is used as the medium of oscillations propagation. The relevance of organizing this connection channel for the optimization of the oil production process is emphasized. The choice of tubing as a medium of oscillations propagation is substantiated. We give an overview of scientific literature that examines fundamental physical propagation bases of elastic oscillation in solid and liquid media. The peculiarities of longitudinal wave propagation in a pipe filled with a water-oil emulsion are examined. We obtained analytical dependencies and computed the levels of oscillations damping for a number of frequencies. The possibility of data transfer in the range of frequencies up to 20 kHz at a distance of 3 km is substantiated. We gave a general preliminary characteristic of the considered communication channel.

Key words: Acoustic communication channel data transfer; Oil well; Propagation of oscillations

INTRODUCTION

In modern conditions of oil production, especially in the long-developed deposits, characterized by high water cut of formations, for the purposes of optimizing the production rate and extending the life of equipment, the issue of monitoring technological operation modes of the well is highly relevant. The decisive factor in creating a modern integrated system for monitoring oil wells or the so-called “smart well” is the promptness of obtaining information characterizing the state of a formation, and the decision-making on the adjustment of the well operation mode on its basis [01, 02].

Some of the main technological parameters of interest are pressure and temperature of the well formation. In addition, due to the fact that the formation productivity is not constant, the level of fluid entering the well must be monitored. The main methods currently used by the vast majority of oil production facilities are the wellhead echometry and the measurement of required parameters with wire submersible sensors [03, 04]. The first method is indirect and has defects due to the changes in pressure, temperature and gas composition in the annular space that affects the speed of sound used in the computations. Also in wells with low gas pressure in the annular space, the generation of a probe pulse and recording of the response are problematic. The second method is more accurate, because the required parameters are read directly in the area of the formation, but it is also economically more expensive as it involves lining the whole length of the well with the geodesic cable. There is also the possibility of using optical fibre, which is a sensor of physical values and an information channel [05]. Currently, the combination of the high-temperature chemical sources of electricity and low-power electronic components allows creating devices capable of measuring the required parameters during the entire service operation interval of the well. In our opinion, the best option is the placement of autonomous sensors in the well and transfer of metrological information to the wellhead data collection equipment. Possible ways to implement a wireless communication channels are examined mostly in the appendix to the well drilling objectives and are an electromagnetic communication channel data transfer via the modulation of a drilling

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agent pressure. These methods have their own advantages and disadvantages [06 - 08].

Thus, one of the problems in the way of optimizing the complexes of technological information collection is the organization of an effective channel for the transfer of metrological data from the formation to the wellhead.

MATERIALS AND METHODS

Within the framework of this article, we will consider the possibility of using an acoustic communication channel, wherein tubing with a water-oil emulsion is considered the oscillations propagation medium. The study on the possibility of using well pipes as an acoustic channel began quite a long time ago [9]. There was also an attempt to implement this communication channel technically [10].

The use of a casing pipe as the transfer channel is not examined due to the fact that its installation is carried out during well drilling, and during its operation the pipe corrodes, changes its structure and thus, its ability to transfer mechanical vibrations.

Relatively high degrees of oscillations damping in gases, and thus high energy consumption for oscillations generation that entail a short battery life of the transmitter get in the way of using the gas medium of the annular space.

Tubing has a minimum contact with external media and is periodically changed in the process of well operation. This may suggest that they are the optimal media for organizing the acoustic data channel. Figure 1 shows a block diagram of the monitoring system for oil wells.

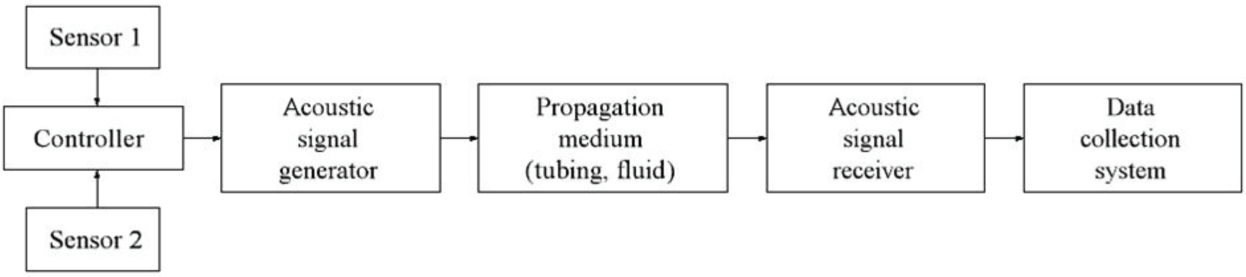

Figure. 1 Block diagram of the monitoring system for oil wells

The controller processes the signals from the pressure and temperature sensors and transmits the data to the acoustic signal generator, which in turn modulates a carrier wave and emits it into the propagation medium, which characterizes the communication channel to a large degree. An acoustic signal receiver demodulates the signal and transmits the metrological data to the collection system for further processing. To assess the effectiveness of the communication channel it is necessary to know its main characteristics – propagation speed and damping of oscillations.

In an unrestricted solid body there are longitudinal and transverse waves with the respective speeds and, which are defined by the formulas:

$$c_l = \sqrt{\frac{\lambda + 2\mu}{\rho}}\ ;\ c_t = \sqrt{\frac{\mu}{\rho}} \qquad (1)$$

where ρ is the density of the substance, λ and μ are Lame constants [11].

For steel $c_l \approx 5.8 \cdot 10^3\,\mathrm{m/s}$, $c_t \approx 3.2 \cdot 10^3\,\mathrm{m/s}$.

Presence of media interfaces leads to the appearance of new types of propagating perturbations – Rayleigh surface waves, boundary waves, etc., which actually means the formation and spread of several waves with different speeds. It should be noted that the above dependencies determine physical processes in unrestricted isotropic media that is why their use for the purposes of considering oscillations in the tubing, with a limited amount, is implemented with some reservations.

Elastic oscillations in fluids are determined by the change in the substance density, so only longitudinal oscillations can propagate in them. The speed of sound in a homogeneous liquid is determined by the formula:

$$c = \sqrt{\frac{1}{\beta_S \rho}} \qquad (2)$$

where β_S is the adiabatic compressibility [12]. For water, $c \approx 1.5 \cdot 10^3$ m/s, for oil $c \approx 1.3 \cdot 10^3$ m/s.

Thus, various oscillations propagation speeds in the solid and liquid media as well as the presence of several types of waves in the solid medium, involve the detection of multiple copies of a signal by the receiver with different time delays.

Weakening of the waves amplitude as a result of its interaction with the medium is exponential $e^{-\delta x}$, where is a way in the medium, δ is a damping coefficient. For solid bodies the damping coefficient δ consists of the absorption coefficient δ_a and the dispersion coefficient $\delta_d : \delta = \delta_a + \delta_d$. During the absorption, the energy of oscillations is converted into thermal, and during the dispersion – leaves the direction of wave propagation.

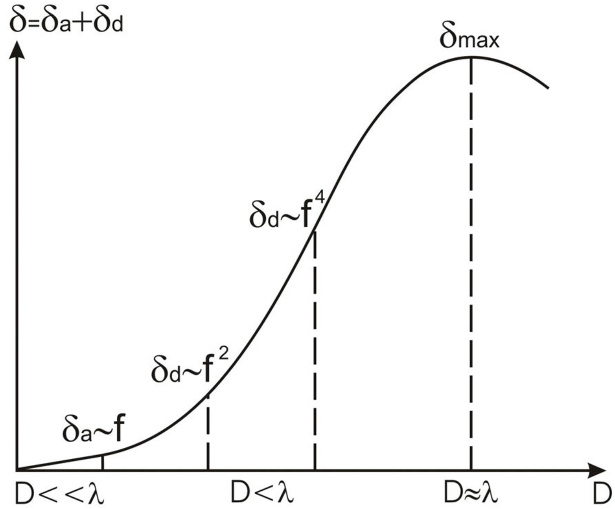

Figure. 2 Dependence of the damping coefficient on the ratio of the wavelength and the average size of inhomogeneities

At relatively low frequencies, where the wavelength λ of an oscillation is much larger that the average size of inhomogeneities D, absorption contributes to the damping the most. As the frequency increases, the contribution of dispersion to the damping increases as well, which reaches its maximum value, when the wavelength becomes comparable to the size of inhomogeneities [13]. Thus, from the viewpoint of minimizing energy losses, the best option is to use the lowest possible frequencies, when the damping is linearly dependent on the frequency. Accordingly, the damping coefficient will equal to:

$$\delta = \delta_a = \alpha f \quad (3)$$

where is a proportionality coefficient, is a frequency of oscillations.

For example, for longitudinal waves in the frequency range of 2-100 kHz in tungsten-carbon steel, in aluminium [14]. In the examined frequency range, where and the damping coefficient is linearly dependent on the frequency, there is no reference information on absorption for the grades of steels, from which tubing is made. Conditionally, let us take the coefficient. Figure 3 shows the dependence of signal weakening at a distance of 3000 meters for a number of frequencies: 2 kHz, 5 kHz, 20 kHz, 100 kHz.

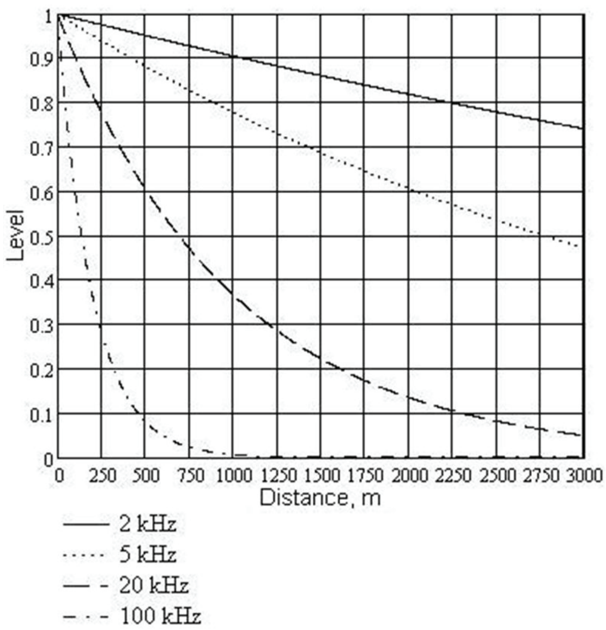

Figure. 3 Dependence of the weakening of the longitudinal oscillations level from frequency and distance

As can be seen from the figure, the dampening level in the frequency range up to 20 kHz is acceptable for the organization of an acoustic communication channel at a distance up to 3 km, which is due the greatest depth of oil wells.

For a travelling plane wave in a liquid, the decrease in its amplitude is also characterized by an exponential dependence. The existing formula of Kirchhoff-Stokes defines a quadratic nature of the dependence of the absorption coefficient on the frequency [15]:

$$\delta_a = \alpha f^2 \quad (4)$$

As can be seen, the dependence of the absorption coefficient depends much more on the frequency in a liquid, rather than a solid body. In addition, the formation fluid is multiphase, i.e. contains oil, water, dissolved chemical substances, mechanical impurities, gas bubbles that are acoustic inhomogeneities. Moreover, their quantitative composition and distribution over the volume change both in time and along the length of the well, and hence, the ability to transmit elastic oscillations changes as well. Based on the above, it can be assumed that it is tubing that is going to be a main medium of oscillations propagation.

CONCLUSION

Thus, we can make a conclusion on the possibility of organizing an acoustic transmission channel of metrological data from the formation to the wellhead in the monitoring systems of oil wells, wherein tubing with a water-oil emulsion is used as a medium of oscillations propagation. In view of the spread of several waves with different speeds, as well as the movement of the water-oil emulsion in the tubing, the given channel can be characterized as a multipath Gaussian channel with a Doppler frequency shift, damping and delay of oscillations in which the elastic wave propagation in solids and liquids is determined by physics.

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