Considering the effect of the logging cable stretching under the influence of its own mass in the well on the accuracy of geophysical parameters determining

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Abstract. The technology of carrying out various geophysical studies of oil wells using a carrying well-logging cable for the delivery of geophysical instruments and equipment is considered in the article. The relevance of the topic results from the need to evaluate the effect of well-logging cable stretching in the well under the influence of its own mass and mass of geophysical instruments and equipment on the accuracy and adequacy geophysical studies. Calculation formulas for determining the well-logging cable stretching under the influence of the geophysical tools and equipment mass without taking into account and taking into account the influence of the carrying well-logging cable mass are also presented. For three types of carrying well-logging cables, calculations were made of their stretching in the oil well under the mass of geophysical instruments and equipment and its own mass, depending on the depth of the investigated well. The analysis of the obtained results made it possible to numerically evaluate the extension of the carrying well-logging cable depending on the depth of the investigated well and by correcting the obtained results it allows to provide the required depth accuracy and reliability of the interpreted results of the geophysical studies.

Keywords - results accuracy, results correction, geophysical tools and equipment, geophysical oil well studies, logging truck, carrying well-logging cable, mechanical characteristics of carrying logging cable, extension of well-logging cable, hydrocarbons production

1. Introduction

At present, hydrocarbons are the main source of energy and raw materials for the production of a variety of products. Despite the development of alternative energy sources, hydrocarbon fuels remain the most widespread and demanded source of energy in the world due to high energy intensity and ease of transportation.

Almost all hydrocarbons in the world are produced by the well method. Bore wells are used for oil and gas production. During the drilling, arrangement and operation of wells, a variety of geophysical instruments and equipment are used. The tasks solved in oil and gas wells by means of geophysical studies in the wells are divided into geological, related to the study of the composition and characteristics of rocks in the sections of wells, technical and technological. The last two groups of tasks include surveying the technical state of open and cased wells, locating the equipment used for hydrocarbon production, and
studying the composition of fluids entering the well. The content of the tasks of these groups is significantly overlapped. The same data (for example, information on the spatial position and profile of the open hole trunk or on the composition of the fluids coming from the perforation interval) are used to immediately correct the drilling and production technologies or fix them for later use (for geomodeling, reservoir development analysis and others) [1-4].

One of the most important among geophysical operations is the determination of the depth of the tool or apparatus location in the well, i.e. determination of the depth of the objects under study.

Various geophysical tools and equipment lowering and lifting is carried out with the help of a lift, a block-balance and a cable. Trigger equipment placed permanently or on the chassis of a car is called a hoist. For carrying out geophysical works, hoists with winches of different sizes and designs are used, depending on the type and length of the cable [4-6]. The general structure of a self-propelled logging truck is shown in Fig. 1.

![Figure 1. Self-propelled logging truck](image)

1. a log hoist with a cable; 2. compartment with geophysical equipment; 3. automobile chassis.

The main means of delivering geophysical instruments and equipment to the well in geophysical studies and shooting-blasting operations is a carrying well-logging cable. A typical design of a carrying well-logging is shown in Figure 2. The well-logging cable consists of current-carrying survey conductors designed to supply power to downhole tools and converters, control devices, and the transmission of electrical signals from these devices (converters) to ground-based recording and processing equipment. Over the insulation of current-carrying survey conductors, armor of two steel wire layers is applied. The lower and upper layers have different direction and thickness, which reduces the unwinding of the cable under the influence of the axial load. The lower and upper layers carry a mechanical load and protect the survey conductors from damage when the cable is lowered into the borehole and wound on the winch.
1. conductor core; 2. the first layer; 3. filler; 4. winding; 5. insulation; 6. the second layer.

The general scheme of carrying out geophysical studies of wells using cable technologies (during wells construction and operation) is as follows:

1. Downhole tools with physical field sensors and electronic components designed to amplify the sensors signals and transmit them to the earth surface via a logging cable, are connected to the well-logging cable wound on the hoist winch drum using standard cable end.

2. The tools are lowered into the well by the well-logging cable through the securely fixed lower roller of the balance block so that the plane of its wheel is perpendicular to the axis of the winch drum and points to its center, and the cable passed through the upper roller of the balance unit is freely lowered into well head. The axis of the lower pulley block balance is connected to the mechanical and electronic depth sensors; on the pulley frame, near the well-logging cable, a depth marker sensor is placed. The depth marker sensor and the electronic depth sensor are connected by cables to the equipment of the logging station.

3. The logging cable is, in turn, connected to the recording equipment of the ground geophysical laboratory, which, together with the log lift, is a part of the field information measuring complex called the logging station.

4. During the lowering of downhole tools into the oil well, the following activities are performed:
   - control of their operability, the lowering smoothness and absence of stops;
   - continuous depth control with the help of mechanical and electronic sensors - depth gauges.

4. The measured parameters are recorded when lifting downhole tools (to avoid errors in depth determination due to the effect of "floating" of the cable and downhole tools in oil wells with a high density of washing liquid). This rule exceptions are geophysical studies of wells by using thermometry, which, in a complex of geophysical studies, are performed first (to prevent disturbance of the temperature field in the well and to avoid temperature errors due to the mixing of the washing liquid during tripping operations).

The purpose of this paper is to assess the effect of stretching of a well-logging cable under the influence of its own mass and mass of geophysical instruments and equipment on the accuracy and quality of performing geophysical surveys of wells.

2. Statement of the problem

To record the geophysical survey curves as a function of the well depth and control of tripping operations, it is necessary to continuously measure the length of the downhole cable or the well depth and transfer the
movement of the cable or drilling tool to the registrars (loggers) and control devices. Such measurements are carried out in two ways: by means of a measuring roller and by reading magnetic marks.

The accuracy of the measuring roller, related to the slip of the cable along the measuring roller and the discrepancy between the estimated roller diameter and the actual cable diameter, reaches ± 5 ÷ 10 m in deep bores. Therefore, the measurement results are used only for visual control of tripping operations.

To determine the depth at which the downhole tool is located in the well, the logging cable is supplied with magnetic or real marks at regular intervals (usually 10 meters). Magnetic marks are the magnetized parts of the cable, while real ones, small bandages made of the insulating tape, are superimposed on the cable.

For a more reliable anchoring to the depths, the marks, multiples of 100 meters, are made different from the ordinary ones. The of magnetic marks reading is carried out with the help of the of depth magnetic marks sensor, which forms the electrical signal “depth - mark” at the moment of passage of the magnetized part of the cable past it. The real marks are visually controlled, while at the time of their passage between the rollers of the cable laying machine a mark is placed on the log chart. The error in measuring depths with magnetic marks does not exceed ± 1.5 m in wells with a depth of 2 km and ± 2.5 m in wells up to 4 km deep [3, 4, 6].

When running operations, the well logging cable is subjected to a complex of various factors. A part of the cable in the well is pulled out under the action of its own mass, the mass of geophysical tools and equipment, and the temperature, which increases by about 1° C for every 30 m. When lifting, geophysical tools and equipment pulling and sticking, friction of the cable against the well walls and high viscosity of the environment (liquid) foster the cable stretching. For these reasons, the cable stretching equals to several meters in wells with a depth of 2 ÷ 5 km and can reach tens of meters in ultra-deep wells [4, 6].

The cable marking is made taking into account its uneven stretching under the influence of tension to provide a sufficiently clear logging of the well-logging records for the depth of depth determination for various operations in the well. Tensions that need to be maintained in accordance with the interval of the cable to be measured are determined from the results of the tension measurements in the wells of the area where the cable will be used, or according to calculated data. The problem of improving the technical and software-methodological support for research and processing of geological and geophysical survey data carried out in horizontal wells is still relevant today. Therefore, the task of improving the calculation methods for determining the logging cable stretching in a well is up-to-date.

3. Theory

It was discussed earlier, that the logging cable is a complex structure of various materials. As a simplifying assumption, we will consider a well-logging cable as a cable made of a homogeneous material. Consider the problem of determining the stretching of a logging cable under the influence of a mass of geophysical tools and equipment suspended on it. According to Hooke's law, the elastic force in the material of the logging cable will be:

$$ F = \frac{E \cdot S}{l_0} \cdot \Delta l, $$

where $F$ is the elastic force in the material of the well-logging cable; $\Delta l$ is the stretching of the well-logging cable; $l_0$ is the initial length of the well-logging cable; $E$ is the modulus of elasticity of the well-logging cable; $S$ is the the cross-sectional area of the well-logging cable.

At equilibrium, the elastic force is equal to the mass of the load suspended to the well-logging cable:

$$ \frac{E \cdot S}{l_0} \cdot \Delta l = m \cdot g, $$

where $m$ is the mass of suspended geophysical equipment and tools; $g$ is the gravity acceleration.
Then, the stretching of the well-logging cable will be described by the following formula:

\[ \Delta l = \frac{m \cdot g \cdot l_0}{E \cdot S}. \]  

(3)

We determine the stretching of the logging cable in the well under the influence of its own mass and the action of mass of geophysical devices and equipment suspended on it. According to the Hooke's law, the voltage in the material of the well-logging cable is described by the following expression:

\[ \sigma(x) = E \cdot \varepsilon(x) = E \cdot \frac{dl}{dx}, \]  

(4)

where \( \varepsilon(x) = \frac{dl}{dx} \) - is the elastic deformation of the logging cable at depth \( x \).

From formula (4), we find:

\[ \varepsilon(x) = \frac{du}{dx} \cdot \frac{\sigma(x)}{E}, \]  

(5)

where \( u \) is the displacement of the logging cable point during deformation.

Let us define the voltage in the well-logging cable at some depth \( x \):

\[ \sigma(x) = \frac{m \cdot g + \rho \cdot g \cdot S(l_0 - x)}{S}, \]  

(6)

where \( \rho \) is the average density of the well logging cable material.

Substituting (6) into (5), express \( du \) as:

\[ du = \frac{\sigma(x)dx}{E} = \frac{(m \cdot g + \rho \cdot g \cdot S(l_0 - x))dx}{E \cdot S}. \]  

(7)

Integrating (7) and performing some transformations, we obtain:

\[ \int_0^l \frac{dl}{E} = \int_0^l \frac{(m \cdot g + \rho \cdot g \cdot S(l_0 - x))dx}{E \cdot S} \Rightarrow \Delta l = \frac{m \cdot g \cdot l_0}{E \cdot S} + \frac{m \cdot g \cdot l_0^2}{2 \cdot E}. \]  

(8)

Thus, the stretching of the logging cable in the well under the action of its own mass is determined by the addend according to the formula (8).

4. Experimental results

Figures 3 - 5 show the results of calculating the stretching of the well-logging cable in a vertical well filled with a liquid. In Figure 1, the curve is obtained by using the formula (3) and the assumption that the entire mass of the well-logging by the action and the mass of the geophysical instruments and equipment suspended on it are concentrated at its free end. Figure 2 shows a curve obtained by using formula 8. In calculations, the mass of geophysical instruments and equipment suspended on a well-logging cable was assumed equal to 100 kg. The mechanical characteristics of the well-logging cables under consideration are given in Table 1.

| Cable brand | Breaking strength min, KN | Stretch ratio, m/km/N | Cable outer diameter, mm | Mass of 1 km in air, kg/km | Mass of 1 km in water, kg/km |
|-------------|---------------------------|-----------------------|--------------------------|---------------------------|-----------------------------|
| KG1x0.75-55-260 | 55                        | 0.3                   | 8.7                      | 329.1                     | 259.5                       |
| KG3x0.2-30-150  | 30                        | 0.5                   | 6.25                     | 160.6                     | 141.7                       |
| KG3x0.75-70-150 | 70                        | 0.2                   | 10.85                    | 462.2                     | 344.9                       |
Figure 3. Stretching of well-logging cable brand KG1x0.75-55-260.

Figure 4. Stretching of well-logging cable brand KG13x0.2-30-150.

Figure 5. Stretching of well-logging cable brand KG3x0.75-70-150.
5. Results and discussion
As it can be seen from the graphs given in Fig. 3 - 5 in the cases under consideration to a well depth of 1000 meters, the calculations according to formulas (3) and (8) have comparable results. At well depths of more than 1000 meters, the use of formula (3) and assumptions about the application of the cable own mass to its free end, result in the almost doubled value for the logging cable stretching, which can lead to a very significant error in the geophysical research results interpretation. When the mass of the cable exceeds the mass of the geophysical tools and equipment attached to it, the application of formula (3) to correct the results of geophysical studies is incorrect. In such cases, the intrinsic mass of the well-logging cable makes the main contribution to its stretching and the use of formula (8) is more correct.

6. Conclusion
In modern economic conditions, it is impossible to organize effective exploration and exploitation of hydrocarbon fields without intensive application of geophysical studies. The leading role in the performance of a variety of geophysical studies is played by the accuracy of determining the position of the tools and equipment used in the investigated well. Increasing the accuracy of determining the position of geophysical tools and equipment in the well during geophysical surveys allows to significantly reduce the time spent on exploration, to increase the reliability of interpreted geophysical research results and to improve the operational characteristics of the developed hydrocarbon field.

The analysis of the obtained results allowed us to numerically estimate the stretching of the carrying logging cable mass depending on the depth of the investigated well. The proposed technique for determining the stretching of the carrying logging cable in the well under the influence of its own mass and the mass of the geophysical tools and equipment suspended on it makes it possible to correct the obtained results and to provide the required depth accuracy and reliability of the interpreted results of geophysical studies.

References
[1] Kearey Philip, Brooks Michael, and Hill Ian 2002 An Introduction to Geophysical Exploration, 3rd ed., Blackwell Science Ltd
[2] Milsom John, Field geophysics. 3rd ed. p. cm. (The geological field guide series)
[3] Kuznecova M A, Cherkovskij N L, and Bahtijarov G A 2014 Method for the determination of corrections of absolute marks in inclined wells and water-oil contact of a multi-layer deposit Geology, geophysics and development of oil and gas fields 11 p 49-51 (in Russian)
[4] Gninev I V., Korolev A B, and Sitnikov V N 2016 Increase of inclinometric measurements accuracy in subvertical wells: Karotazhnik journal 12 (270) p 98-113
[5] Korjakin A G, Larin Ju T, Mesenzhnik Ja Z 2015 Some actual problems of submersible cables. Part II: Photon-Express 4 (124) p 32-34
[6] Konjuhov V M, Krasnov S V, Konjuhov I V 2016 Computer modeling of implosion processes in the oil reservoir system - well - mobile implosion chamber in: Automation, telemechanization and communication in the oil industry 5 p 32-37