Metrological support of geophysical equipment for acoustic logging

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Abstract. The system of metrological support of geophysical well surveys (GWS) is a system of technical and methodological tools ensuring unity, reliability and accuracy of measurement results. For acoustic logging devices, physical standards with highly stable properties were developed and implemented. They are based on simulation of attenuation and time delay of elastic waves propagating in casing pipes. The design of a calibration device for acoustic video logging equipment made it possible to increase research reliability. The design of a field calibration device allowed for rapid calibration of acoustic equipment in field conditions for improving the GWS quality.

1. Introduction

One of the relevant problems dealing with quality of information [1] obtained by acoustic devices is metrological control of measurements [2]. Improvement of the reliability of measurement results and reduction of the systematic component of measurement errors can be achieved through calibrations using measurement tools, standard measurement and test methods, systematic assessment of accuracy of measuring tools, and regular training of personnel engaged in measurement and testing processes.

Calibration measurements aim to check stability of the entire electronic path of the equipment during setup and measurement processes, assess the compliance of measuring equipment with its passport data, ensure required recording. They are carried out before the studies and after using electronic circuits of amplitude and time calibrators located in the measuring panel and are carried out according to the developed technique.

Calibrating measurements establish the relationship of measured amplitude-time parameters of the acoustic signal with the physical state of the medium [3]. They are carried out using physical standards - natural models of the casing with different conditions of the cement ring or real environment simulators in the form of reservoir models intersected by a borehole with acoustic parameters certified using model measuring channels.

When calibrating acoustic logging equipment, including registration of the full wave packet, the following metrological characteristics are evaluated:

- interval time of propagation of an elastic wave per unit length (μs/m);
- attenuation coefficient – attenuation of the elastic wave per unit length due to its absorption, scattering and divergence (dB / m);
- basic measurement errors for the interval time of propagation of elastic waves;
- basic measurement errors for the damping coefficient of elastic waves;
- the main frequency of the radiator under the main operation modes;
- the attenuation coefficient measurement range at frequencies varying from 6 to 40 kHz;
- the dynamic measurement range of acoustic parameters of elastic waves at different frequencies and for different lengths of acoustic probes;
- acoustic pressure developed by the emitter during the main operation modes reduced to the standard conditions of the free field;
- identity of the measuring channels for the conversion factor;
- non-uniformity of conversion characteristics of the measuring channels.

At present, there are a large number of field (PAUK, UPG-3P) and stationary (UPAK-1, UPB-AK) devices [4], which are used to calibrate acoustic logging equipment and acoustic cementing quality control measuring $\Delta t$ and $\alpha$ [5].

2. Methods and material

The results are based on the analysis of literature data, experimental and analytical methods.

3. Research and efficiency assessment

The parametric range of compact acoustic logging devices systematized by the author and implemented by the VNIIGIS Company consists of three layout lines (wideband multi-frequency acoustic logging, noise acoustic logging and acoustic video logging) designed to monitor the technical state of oil and gas wells. It allows for choosing the layout depending on the nature and complexity of geological and technical problems.

To calibrate the acoustic equipment, it was necessary to develop [6] a metrological support system. The metrological support system was developed and implemented (Figure 1). At the first level of the system, primary transducers are calibrated [7], at the second level, functional units and simple layout modules are calibrated, and at the third level, complex devices are calibrated. Calibration of the electron-acoustic path [8] of the acoustic video logging equipment involves checking the static sensitivity of the amplitude channel and dynamic resolution of various types of defects.

3.1. Stationary tools of metrological support based on physical standards

Calibration units [9] based on physical standards allow for simulation of the effect of all well defects on acoustic parameters. The parametric tools work on the non-linear section of the current-voltage electronic path. The measurement error can be 25–30 % even with a slight inaccuracy (up to 5 %) in the operating point [10]. The works aimed to reduce measurement errors resulted in the development of a set of physical standards in the form of steel pipes with an inner diameter of 104 mm, a length of 3700 mm, and a wall thickness of 5 mm. On the outer surface of the pipes, defects were made in the form of grooves 5 mm in width, 2.5 mm in depth. The increment was 15 mm. The size of the defect area of each pipe varied depending on the attenuation of elastic waves required for each specific model. Simulation of defects [5] made it possible to reproduce the required range of changes in dynamic and kinematic parameters of elastic waves corresponding to real defects.

Calibration measurements of the amplitude-time characteristics of elastic waves propagating along the pipe walls of physical standards were performed using a special measuring sliding probe equipped with a certified hydrophone. The values of attenuation coefficients reduced to the measuring base of 1.7 m are presented in table 1.
Figure 1. The system of metrological support of the parametric range of compact acoustic complex equipment.

Table 1. Summarized table of attenuation coefficients and elastic wave distribution time at different frequencies in the calibration tubes of physical standards.

| No of the pipe | Base Attenuation Factor | Distribution time |
|----------------|-------------------------|------------------|
|                | $\alpha_m$ | $\alpha_t$ | $\alpha_k$ | $\tau_n$ | $\tau_m$ |
| 1              | 6.8        | 6.1        | 7.0        | 8.2      | 272       | 272       |
| 2              | 13.9       | 9.9        | 16.1       | 14.5     | 291       | 285       |
| 3              | 24.0       | 12.2       | 22.3       | 19.5     | 312       | 285       |
| 4              | 29.0       | 28.0       | 37.0       | 31.2     | 326       | 299.2     |

Strength properties of the cement stone and the vertical channel opening angle are assessed using the developed model stationary calibration systems with cement rings of various compositions and strengths. The pallet dependencies make it possible to determine values of various cementing defects (cement strength, openness of volume-contact defects, etc.) with an accuracy of 30–40 % if well conditions correspond to calibration conditions, and with an accuracy of 50 %, if they do not correspond to the calibration conditions [5]. However, instability of the parameters of these physical standards limits the scope of their application. Calibration units based on a universal set of calibration tubes have significant advantages over physical standards based on cement mixtures. Acoustic characteristics of the calibration tubes are set in such a way as to cover the necessary range of their changes that occur in real conditions of cased wells. Physical standards are tested using real downhole tools certified on basic calibration systems which can serve as a reference for comparative measurements.

The calibration technology establishes a relationship between acoustic parameters that are not validated using standard means ($A_k$, $A_r$, $t_p$) that characterize the acoustic properties of physical standards ($\alpha$, $t$). This relationship is expressed as a calibration dependence which allows for transition from amplitude parameters measured by two-probe equipment in a linear scale to attenuation parameters measured in a logarithmic scale. Each frequency has its own calibration curve.
The calibration technology involves the following stages. The device is moved from one physical model to another registering the values of the relative amplitudes of the elastic waves and comparing the obtained values with the calibration curves. The device has been calibrated if the discrepancy between the received and calibration values of the parameter being calibrated does not exceed the limits specified in the technical specifications for the equipment. To calibrate the tool by measuring parameters, physical standards based on calibration tubes certified by general technical measuring instruments are used.

Amplitude and time channels of the acoustic probes for an open barrel are calibrated in the same reference media. The operation of equipment is satisfactory if the amplitude of the longitudinal wave at the input of the measuring panel, when the tool is in the metal pipe, is \( \geq 2 \times 10^{-1} \) V, the difference between the elastic signal attenuation coefficient \( \alpha_m \) and \( \alpha_{ref} \) is no more than 2-3 %.

According to the principle described above, the UP-3 calibration device for acoustic video logging equipment was developed and implemented. It consists of a core, a set of certified calibration cylinders corresponding to different casing sizes with artificial defects on walls (cracks, holes dimensions, etc.), a lever used to simulate the tool movement.

All calibration measurements are recorded by a PC using a ground-based digital recorder of the “GECTOR”, “Vulkan V3” in the “CALIBRATION” mode using data in the recording and processing modes.

3.2. Field equipment for metrological support
For field conditions, the CPK-1 field calibration device was developed and implemented. It consists of a sound pipe covering the entire probe length of the calibrated device with a unit generating high pressure and three removable dampers creating a required level of signal attenuation corresponding to signal attenuation in the real casing and providing the required the dynamic signal recording range.

The advantages of this device is efficiency and reliability of calibration operations achieved by a pressure boosting unit which eliminates the influence of gas dissolved in the fluid filling the unit. One more advantage is a simple technical solution that ensures mobility of the device.

4. Conclusion
Acoustic research quality enhancement is impossible without solving the problems of metrological software which should be an integral part of the entire technological process from equipment designing to solution of geological and technological problems.

Physical standards with stable properties were developed and implemented for acoustic tools based attenuation simulation and time delay of elastic waves propagating in casing pipes. The design of the calibration device for acoustic video logging equipment was developed and implemented which made it possible to increase the reliability of research.

The design of the field calibration device was developed and implemented which made it possible to ensure prompt equipment calibration in field conditions.

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