The high resolution ultrasonic well imager

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Abstract

The paper describes the architecture and technical characteristics of the developed high-resolution ultrasonic borehole imager. Using the examples of comparing ultrasonic data images of well logging with core photos, its shown resolution in detecting fine details of a well with an opening of ~ 1 mm and others.

1. Introduction

Acoustic imagers application for the study of the borehole wall was first proposed in 1969 by Zemanek et al [1]. This logging tool with a working frequency of 2 MHz was called an acoustic televiewer. Subsequently, this class of equipment received the general name of formation microimagers. The demand for this equipment is increasing every year [2, 3, 4, 5]. The improvement of this class of tools is primarily aimed at increasing the resolution (the number of points per sensor rotation around its axis). A description of a new specimen of a high-resolution borehole ultrasonic imager (HRUI) is presented, and the general scheme of the tool is given in this paper. The fundamental novelty of HRUI is the complete recording of the full wave signal reflected from the borehole wall into the internal memory of the device, which required the use of non-standard approaches to work with electronic components. Main tasks are to demonstrate the principles of recording and signal processing and show the results of borehole tests. The correctness of the received information is confirmed by photos of the core extracted from the borehole.

One of the important tasks of the borehole logging is to study the well surface for cracks detection. In the case of an open hole, the main tasks in the study of cracks are opening diameter, falling azimuth, extension, and its formation. Recently, the necessity of studying and detection of low-porosity or fractured reservoirs has increased. Except for the cracks, more interest in the open hole is also have the studying of the geological features of the section. It may affect to the well drilling, in particular, thin streak or lenticular shale layers during drilling, which may lead to deformation of the well surface under the influence of drilling mud. In the case of a cased hole, the main task is to clarify the results of cement-bond sonic logging, in particular, to identify the type of cement stone defects and to thicken the producing column. Such violations of the producing column and cement stone can lead to a vacuum rating column itself and annular circulation along the longitudinal cracks or ring-shaped clearances.

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Often during drilling, the wells are filled with drilling mud. In this case, optical methods are not suitable, and the high-frequency acoustic methods are better for the detection of the borehole surface thin structure. For these purposes, the high-resolution ultrasonic imager HRUI was developed and described in this paper.

2. Structural scheme description

The structure of the hardware scheme of the HRUI is shown in Fig. 1, which consists of the following modules: 1) digital control system based on FPGA - CYCLONE IVGX; 2) power switches (for piezoelectric transducers generating); 3) spatial orientation (accelerometers and magnetometers); 4) data acquisition; 5) gamma-detector; 6) power switches (for data exchange with a logging station); 7) SD-card slot; 8) stepping motor with its driver.

The main part of the HRUI logging tool is the digital control system based on FPGA-CYCLONE IVGX, which includes: generation of transition signals, parallel collection and processing of information from several analog-to-digital converters (ADCs, which digitizes signals from piezoelectric transducers), control of step-motor, acquisition of spatial orientation data and gamma detection, sending data to a logging station, recording the data on a storage device (on an SD card).

The algorithms of the digital control system were initially tested in a laboratory model of the imager, which was based on FPGA development kid [6, 7]. Modern circuit debugging systems inside FPGA can be performed using a JTAG interface (such as the Signal Tap in-circuit logic analyzer), it needs a large number of logic elements and memory, allowing to observe in detail any selected internal signals or nodes. The schematic solutions of the layout are easy can be copied to another FPGA chip, as it performed in the HRUI imager. Because of these advantages in debugging the laboratory model of the imager is used now for new algorithms testing.

To detect the amplitude maximum and determine the caliper value the sampling frequency is chosen equal to twice the transmitted frequency. This sampling frequency is close to the limiting frequency (5 Mbit/s) for 14-bit ADC, which are capable in the automotive temperature range. Such frequency parameters are realized in integrated ADCs based on digital-to-analog converters (DAC) on the principle of capacitive voltage dividers recharging, and they are distributed by many manufacturers (Analog Devices, Maxim, Texas Instruments, etc.).

When recording a temporary data window, this ADC mode creates a sufficiently powerful information stream, which only SD-cards with a recording rate class of at least 10 or UHS can write.

The data logging algorithm of the imager is followed: a command is sent from the logging station, which contains information about the diameter of the well and the current depth. HRUI begins to rotating the stepper motor to a frequency of 600 rpm and responds to a logging station with the following information: stepper motor speed, azimuth and zenith of the well and imager, amplitude and caliper images, the current amplitude of the signal in the time window for one single measurement (as oscillogram).

For each stepper motor turn, the 400 measurements are carrying out using piezoelectric transducers. In each measurement, pulses with a frequency of 800 kHz are applied to these transducers, at the next step the ADC-controller collects information about the total signal amplitude in the time window and other technical information, and sends this data packet to the SD-controller module, where data is recorded on the SD-card. This method of the signals amplitude recording does not require the setting of the initial range and amplitude threshold but uses a large amount of digital information. So a 32GB SD-card can write interval with ~ 800m long with a logging speed of 150m/h. After the completion logging, the data from the SD card is read and processed on a personal computer. The results of the research are described in the next section.

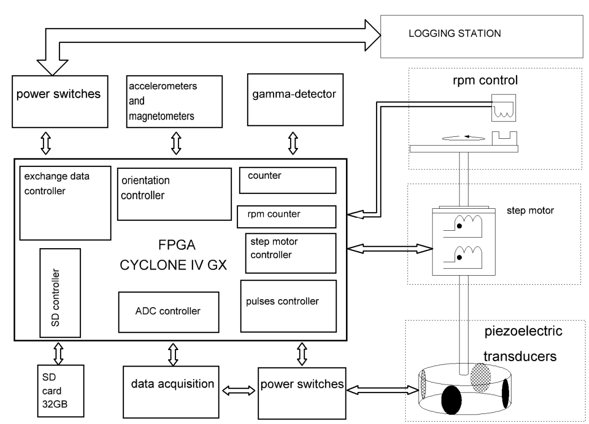

Fig. 1. The electronic circuit structural diagram of the HRUI ultrasonic imager

3. The interpretation of HRUI borehole test

Testing of developed logging tool was carried out in the well of the Institute of Geology and Petroleum Technologies of Kazan Federal University, Kazan. The total depth of the well is 300 meters. In the depth range from 100 to 300 meters, the well has an open hole. The nominal diameter of the well open hole section is 216 mm. Core sampling was carried out throughout this interval. The diameter of the core in the research depth is 92 mm. The total core length was 187 m [8].

Stratigraphically the rocks are related to the Urals section of the Permian system and the upper section of the Carboniferous system. Geologic formation is represented by interbedding of dolomites, anhydrite, and gypsum. Throughout the borehole, there are interlayers and lenticular inclusions of gypsum, anhydrite with a thickness from 10 to 50 mm, as well as subhorizontal and vertical slit-like leaching cracks with an opening of 1 to 5 mm. In addition to cracks, slot-like caverns are present with an opening of voids from 2 to 50 mm. From a depth of 200 m, there is a small amount of clay material in the form of a cementing substance.

Based on the tests results of the ultrasonic data processing of the logging tool, processed by the procedure described above the images of amplitude and caliper were obtained

Fig. 2 show the image of amplitude and caliper values at a depth of 99.05 meters, there is leaching crack visible, which is partially healed by gypsum. The photo of the core fragment is clearly shown it in the right part of Fig. 2. According to well logging and core photo a 2 mm opened leaching crack is clearly visible at a depth mark of 99.1 m.

Fig. 3 shows another fragment of the results of data processing, obtained during the tests of the downhole tool. One mm leaching crack with an azimuth of 320°is clearly recognized at the image of the amplitudes at a depth of 102.76 m. This crack is characterized by a drop in the recorded amplitude of the signal. This object is also visible in the core photo. A thin layer of dolomite (35 mm in thickness approximately) is recognized inside the matrix of high density anhydrite at a depth of 103.08 m. In the image of the amplitude, this layer is characterized by lower values of the amplitude. In the caliper image, it is characterized by an increase in the diameter of the well, most likely due to a decrease in density and erosion. Below, in the interval of depths of 103.1 - 103.4 m in the azimuth of 145°, a vertical crack is displayed.

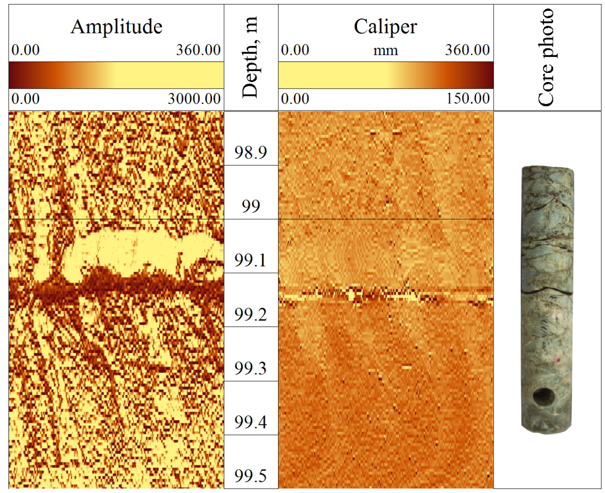

Fig. 2. The example of the leaching cracks detection according to HRUI data.

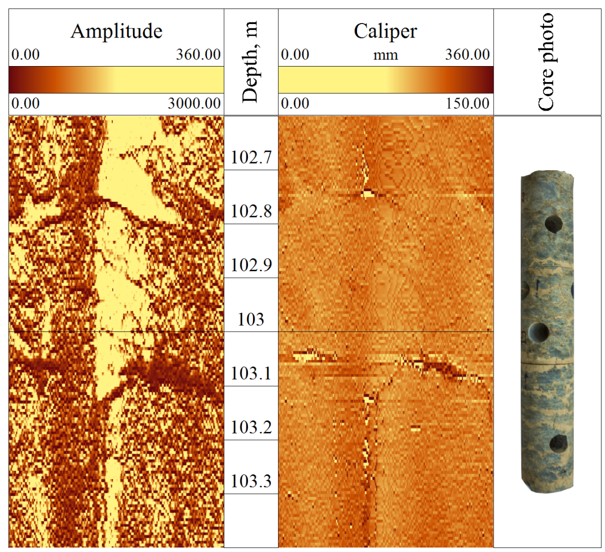

Fig. 3. The example of interlayers and vertical cracks detection according to the HRUI data.

An interesting fact is that in the Fig. 4 shows laces from the drilling tool that appeared in the conditions of the well drilling. The laces are traced in the interval of 123 - 123.6 m and clearly visible in the photo.

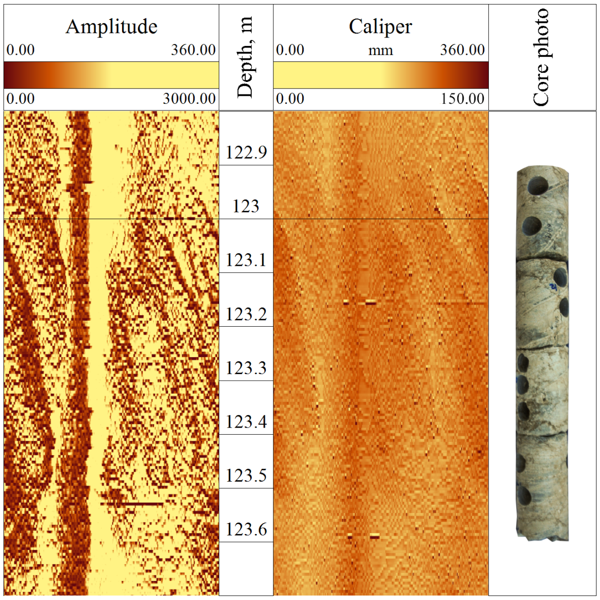

Fig. 4. The example of the drilling tool laces detection.

On Fig. 5 the traces of leaching are well recognized from the depth of 135 m and to a depth of 135.3 m. The core photo clearly shows traces of few caverns with a width of about 3 mm, which partially healed by anhydrite.

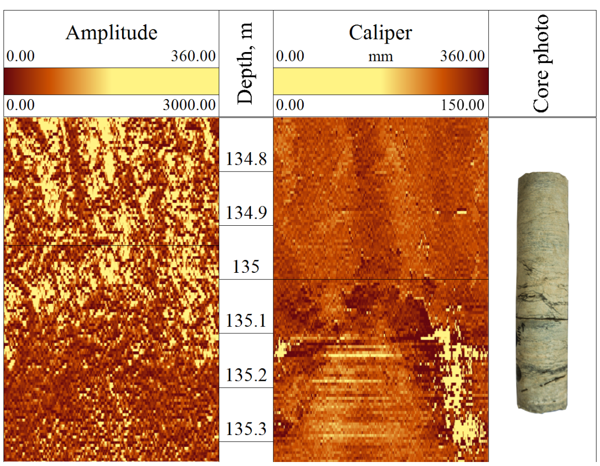

Fig. 5. The example of azimuthal leaching cracks detection according to HRUI data.

4. Conclusions

The logging tool of high-resolution ultrasonic imager HRUI was developed. The paper describes the architecture of the digital system, data processing, and the obtained results. Logging image and well core photos were compared.

Successful tests of the well logging device (HRUI) were carried out. Images of amplitude and range were obtained. The analysis of the obtained information makes it possible to clearly identify various structural and textural elements in the section of the well:

- boundaries of the reservoir with contrasting acoustic properties;
- cracks and caverns formed by the result of leaching and cracking of the rock mass.

The analysis of the obtained information allows obtaining new geological information about the section of the well.

HRUI can detect cracks with an opening of 1 mm, which is confirmed by a comparison of obtained borehole images and core photos. The position of the cracks can be different, as is shown in Fig. 2 (the crack is subhorizontal), and in Fig. 5 (the crack is azimuthal). In addition, the mechanical action of the drilling tool in the form of spiral laces can also be recognized. All of these it can be concluded, that HRUI has a high resolution of the image. An above-described result concludes that HRUI tool can record the high-resolution image.

5. Acknowledgments

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