Sonic Testing of Long Pipes by Using Longitudinal Waves

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Abstract. *Application of the sonic testing technique is considered in the context of the detection of defects of long pipes and bond of various materials to the surfaces of pipes. The characteristic property of the proposed technique is that the longitudinal waves at 1 – 20 kHz are used for inspection and only single-sided access is needed for transducers located at a head of a pipe. Some characteristic features of the technique and details of the construction of the sonic testing apparatus are considered.*

Keywords: Sound, Sonic Testing Technique and Apparatus, Long Pipes, Defects, Cementation

1. Introduction

The sonic testing (ST), an especially ultrasonic testing (UT), is the well known technique for material testing [1, 2, 3]. The maximum detection range of a sonic sensor is typically longer for lower frequencies, while the resolution and accuracy are typically better at higher frequencies. Therefore low frequencies of sound should be used for long subjects of testing such that large dimensional pipes. The aim of this paper is to study of possibilities of the sonic testing using longitudinal waves for detecting defects of the structure and bond of various materials to surfaces of long pipes. Mainly discussion is devoted to cement bond logging.

2. Subject and Methods

Usually the transverse waves are used to determine the quality of the cement bond to the production casing, and to evaluate cement fill-up between the casing and the reservoir rock. This technique has been called Acoustic Carottage of Cementation (ACC) (Synonyms: Acoustic Well Logging, Cement Integrity Logs). The technique is invasive. The inspection is carried out by equipments that are located in the inner space of oil wells filled by a liquid. This often used ACC technique has a very good sensitivity, but is very expensive in practice.

In 1992, it was suggested by Kozlov A.V. et al [4] that the inspection the quality of the cement bond to the production casing can be performed by the nondestructive technique, by using longitudinal sonic waves. The technique was designed for "express technology out-of-well cement logging''. The characteristic property of the proposed technique was that the longitudinal waves are used for inspection, and only single-sided access is needed for transducers located at a head of a pipe. The equipment has been elaborated for sonic inspection of oil wells at relatively low frequencies (20kHz). This low-cost technique was named Vibroacoustic Cementometry (VAC) and used for preliminary inspection of oil wells during for more than ten years. This former home-made system has been made using IBM AT personal computer and C++ program. At the last time, the testing system was reconstructed anew by the authors using the modern electronics, notebook and National Instruments LabVIEW program. This system is described in the presented paper.

3. Apparatus

The important terms often used in sonic inspection to describe a technique's ability to locate flaws are the wave velocity υ, frequency *f*, wavelength λ, attenuation coefficient α, sensitivity and resolution Δx. Sensitivity is the ability to locate small discontinuities. Sensitivity generally increases with higher frequency. Resolution is the ability of the system to locate discontinuities that are close together within the material or located near the surface. Resolution also generally gets better as the frequency increases and can be evaluated as $\Delta x \approx \lambda/2$. The attenuation coefficient α increases with frequency sufficiently rapidly as $\alpha = k_1 f + k_2 f^n$, n = 2..4. These facts lead to the conclusion that low frequency sonic waves are better to use for inspection of long multilayer pipes. Thus, frequencies equal to or higher than 1 kHz have been chosen to use in the apparatus elaborated.

The elaborated inspection system consists of several functional units, such as the pulser/receiver (home-made), transmitter and receiver transducers (home-made), display devices, analog-to-digital (ADC) and digital-to analog (DAC) converters produced by the Nationals Instruments, computer ASUS"EeePC1000H" and power supplier.

The elaborated pulser is an electronic device that can produce electrical pulses up to 3 kV of amplitude. Driven by the pulser, the transmitter transducer connected to an amplifier through the electric transformer generates sonic energy at desired frequencies in the range of 1..20 kHz. The generation of the carrier is fulfilled by the computer. The length of the pulse can be changed from two to ten cycles of a carrier. The sound energy is introduced into the pipe body through its head. The acoustic contact between the transducers and the surface of the head of a pipe is provided through the slice of alabaster (gypsum) or other contact liquid. An acoustic wave propagates through the pipe. When there is a crack or partial bond with cementation in the wave path, part of the energy will be reflected back from the flaw surface.

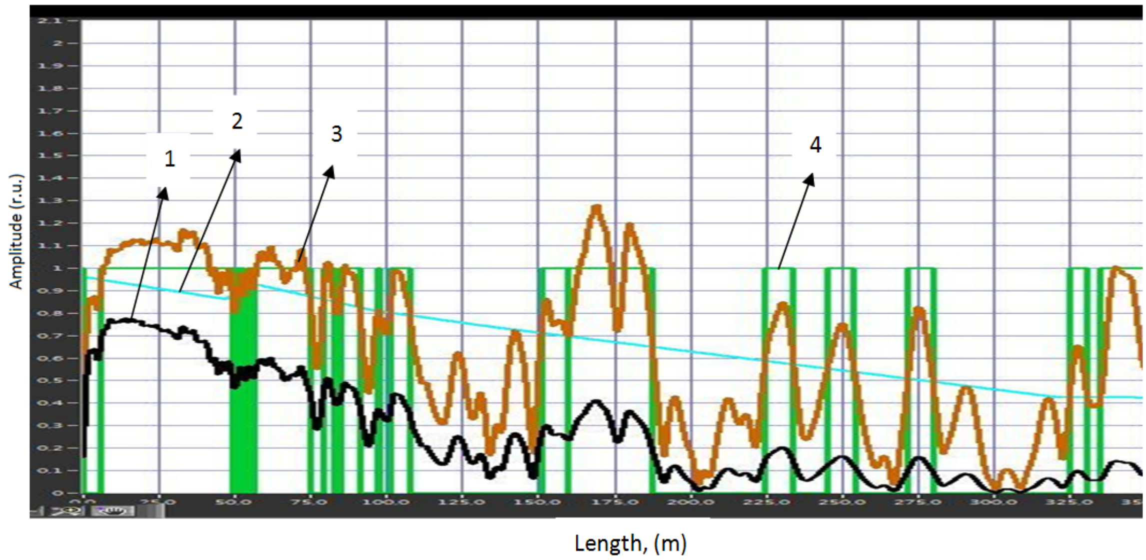
The receiver transducer is situated also at the head of a pipe. The reflected signal amplitude is displayed versus the time from signal generation to that when an echo was received. The signal travel time can be directly related to the distance that the signal travelled. Sound velocity in the body of steel pipes of oil wells was estimated as being 5150 m/s.

The home-made transducers were employed for measurements. Lead zirconate titanate ceramic compositions produced by "Avrora" enterprise, Volgograd, Russian Federation, were employed. The preamplifier was placed immediately into the body of transducer. The crossed diodes were used to protect receivers during the large amplitude signal of the pulser.

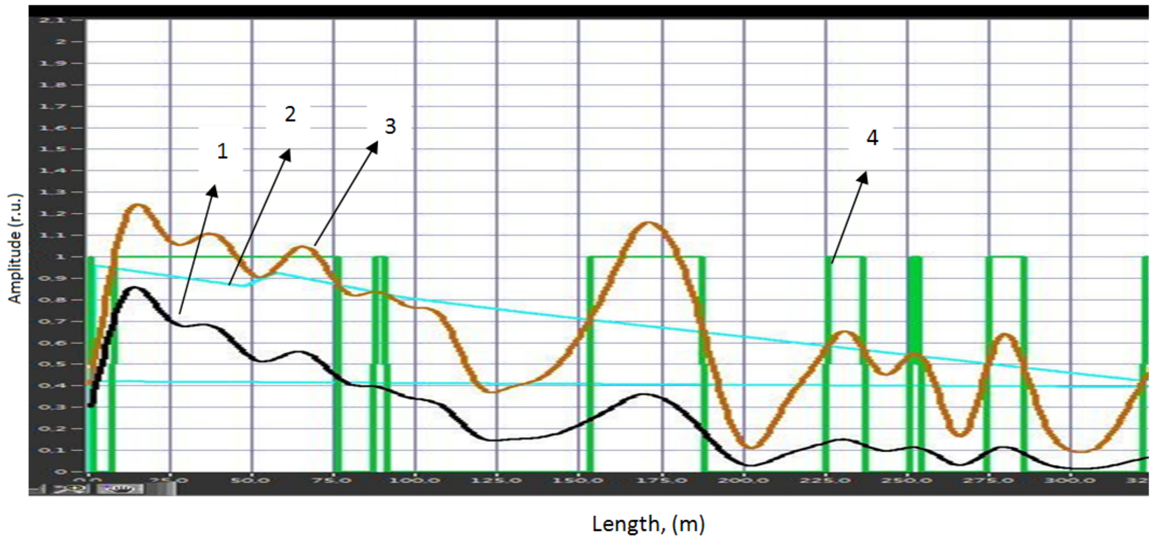
The usual ASUS"EeePC1000H" netbook was used to control the system and process of the data. All parts of the software were elaborated in the National Instruments LabView environment. M Series Multifunction DAQ for USB-16-bit, 250 kS/s, produced by NI, was chosen to perform analog-to-digital and digital-to-analog conversion. The software contains parts for signal acquisition, averaging, smoothing of measured values of signal amplitudes, evaluating of a "midline", approximating the midline by the exponential functions, dividing the smoothed experimental line by the midline, cut off the noise level, and other final transformations of the measured curves into the cement bond logging curves.

The batteries (accumulators) were used in the power supplier. The possibility of charging the batteries was also taken into account. The cable equipment consists of cables for power supplying, transmitting to and receiving of electric signals from the transducers. The length of the cables is 12 meters to perform measurements from the remote automobile. The inspection system is portable because being placed in the two small suitcases (40x35x20 centimeters), one of them for the processor and measurement units and other for the cables and transducers.

4. *Experimental results*



a)



b)

Fig.1,a (top). The curve 1 is the sonic signal amplitude after the rectifier and low-pass filter versus the distance from the head of the well (length). The curve 2 is the normalized exponential approximation of the curve 1. The curve 3 is the measured curve 1 normalized by dividing point-by-point by the exponential curve. The curve 4 is the threshold curve depicted as rectangles indicating the location of defects along the well pipe detected by the other method of well logging.

Fig 1, b (bottom). The curves 1 and 3 after the procedure of calculation of moving average over given range of sampled values.

The experimental testing was performed at frequency 1 kHz for comparision at the well with the known construction and with the available results of the previous inspection by the usual sonic well logging ACC technique. The example results are presented in the figures.

5. Discussion and conclusions

The tests executed on the real oil wells shown capacity for work of the elaborated inspection system for pipe length up to 300 meters. The results of the system coincided with the results of the acoustic well logging in more than 80% of localised defects.

By our opinion, this elaborated system for vibroacoustic cementometry will be, in some cases, an alternative to the well known systems of acoustic well logging because its low price. The ACC is invasive because the inspection is carried out by equipments that are located in the inner space of oil wells filled by a liquid. The inner well equipment should be extracted before testing by the ACC technique. Therefore the ACC technique is much time more expensive than the VAC technique.

The authors recognise that much work should be done to bring the technique to perfect.

The technique has advantages that are usual inherent to all sonic echo techniques [1, 2, 3]. Here the main of them can be repeatedly listed: a) Only single-sided access is needed. b) The measurements require only short time (within 30 minutes). c) Detailed measurements can be produced with automated systems.

Sonic inspection also has its limitations, which can be here itemized: a) Surface must be accessible to transmit sound. b) Linear defects oriented parallel to the sound beam may go undetected. c) Reference standards are required for both equipment calibration and the characterization of flaws. d) Resolution is limited by half of the wave length. c) Outside sounds and noises are the serious hindrance to perform correct measurements. d) A signal-to-noise ratio exponentially decreases with the distance from transducers. This fact leads to serious problems for inspection of very long pipes.

References

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