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Diagnosing the Bottom of the Vertical Tank, a Device Based on the Phased Acoustic Gratings

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Abstract. This paper presents a decision on the creation of a specialized low-frequency flaw detector operating on acoustic phased arrays. A defectoscope will solve the problem of oil leakage through diagnostics of installation or operational defects of the bottom base metal sheets that are difficult to detect by conventional methods of testing due to a large area of the object.

1. Introduction

The most dangerous type of wear in the operation of vertical steel tanks is the formation of leaks in the leaf elements of the walls and bottoms due to corrosion under exposure to the external environment and possible contamination (precipitation) in the stored petroleum product. The adverse effects of leaks are loss of oil, increased fire risk, environmental pollution and undermining the base of the tank [1]. In this regard, the "Rules of technical operation of tank farms" provides periodic measures for tank diagnosis.

In the majority of typical methods for control of the tank bottom, attention is paid to the inspection of welded joints. However, the welded connection of the heads during operation of the tank is not exposed to high tensile loads, and therefore, it they may be tested for tightness only. On the bottom made of rolls welded by automatic and semi-automatic welding, inspection by ultrasound [2] should be performed only for mounting seams, and such welding defects as non-through the fusion, undercuts, pores and removing toxins are unlikely to pose any danger. However, much more actual control is that of the base metal sheets. For example, according to statistics of weld observations, not more than 10% of the total detectable leaks are in the bottoms of tanks [2, 3].

Distinctive features of the exploitation of oil reservoirs in terms of the mechanisms of wear of the walls and bottoms are loading and the predominance of chemical effects of the environment on the activity of the stored product.

In view of the accessibility of leaks in the vertical walls of the test tank and in the course of their operation for visual inspection, their detection does not pose practical difficulties, and chemical effects of the environment on the metal walls are predominantly one-sided (outside) and less active than those on the bottom. Visual detection of leaks in the bottom with full tanks is impossible.

Removing the static pressure significantly alters the current state of the defects in the bottoms. Through or penetration defect occurring potentially under pressure from the liquid column gets crack opening sufficient for penetration of the product, but when unloading the tank under the action of elasticity of the metal it can be drawn together to the extent that it is able to detect defects visually. Operational defects arising from the soil are available for visual identification regardless of their size.

2. Results and Discussion

Typical methods of the control of the bottoms of tanks listed in the instructions, provide for selective testing of visually suspicious places with ultrasonics (weld and thickness measurements), and vacuum-liquid method (through defects). The vacuum-liquid method implies that a suspicious part moistened with soapy water is placed in a transparent vacuum chamber (hood Plexiglas), with the air evacuated. Under atmospheric pressure, the air rushes from the bottom into the camera through the defect, and therefore, the defect forms bubbles [4, 5].

However, such methods do not solve a number of problems, namely: they do not reveal defects in the form of ulcers and non-through cracks that develop from the soil, and also through the "collapsing" cracks that cannot be distinguished visually because of their weak erections when unloaded RVS. To solve this problem a special technique of continuous ultrasonic flaw detection was developed using normal acoustic waves in the leaves (Lamb waves). This enabled, for example, full control of the bottom vertical tank for storing diesel fuel with a diameter of 18 m (an area of 2550 m^2) with the cost of finding defects of 8 man-hours. However, the drawback of this technique is that it is focused on the parameters of the model universal ultrasonic flaw detectors, manufactured by domestic (UD2-12, UD2-17) and foreign (USK-7S) industry at the time of its development, which do not always most correctly satisfy this task.

This primarily refers to a set of ultrasonic frequencies stipulated by the standards for such equipment. The most universal flaw detectors use frequency below 1 MHz, which limits the "range" of the acoustic signal as the frequency increases, and its tendency to fade increases. The developed method works for the "range" of 1 m. If we start not from the universal instrument and the conditions of the problem, the optimal frequency should be considerably lower than that realized in the method versions (1–2 MHz). Moreover, in recent years, in the global market of flaw detection equipment, computerized models with low ultrasonic frequencies such as UD3-103 "Peleng", UDS 2-52 "Probe" and USM-22L appeared.

However, the selection of hardware is only a part of the solution of the technological tasks of ultrasonic diagnostics of individual facilities. Each task of this type requires optimal selection, and at the best case, it is special design and manufacture of the piezoelectric transducer (sensor) for the most efficient transfer of oscillatory pulses of electric energy into ultrasonic probing signals of elastic oscillations of a selected type in a specific metal object and return of the acoustoelectric conversion echo from all possible defects.

Currently, many developers of ultrasonic flaw detectors turned to the use of the so-called PAAG-converters ("PAAG" is phased array acoustic grating). They are convenient to use since the insertion angle can be changed automatically, that is, it scans a swinging beam. The general scheme and principle of operation of phased arrays is shown in figure 1.

A phased array radar is piezoplasty frequent cut into narrow strips (width is approximately equal to the length of the longitudinal wave in the material, which is pasted on the lattice). Each lane corresponds to an individual channel for radiation-reception of the inter-channel phase shift, the value of which is adjusted automatically. The principle of operation of the PAAG is based on the common mode interference of waves (figure 1). If the phase shift between the fronts of both bands is zero, the same edges 1a and 1b and the following one, spherically spreading, will be in phase overlap between the strips at the point sliding straight down. At this point, the signal is always twice as weak as in the other points of the single-phase fronts. Therefore, its trajectory along the total acoustic axis is shown for two bands. If the phase shift is not zero, the intersection points are the same, and the fronts are moving. The greater the phase shift, the greater the angle of the beam. The increase in the number of lanes expands the wave flow.

The phase shift between the radiation channel and the reception one is created in the instrument using electronic circuits made of simple elements called delay lines (two resistors and a variable capacitor, which determines the shift value).

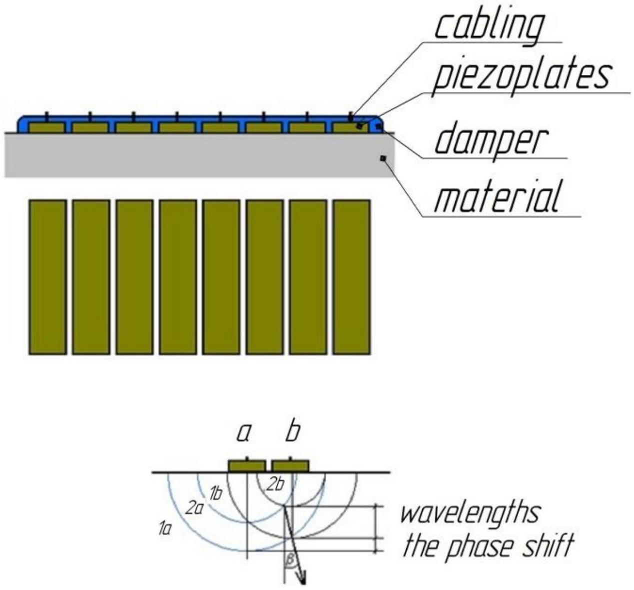

Figure 1. The general principle of operation of phased-array acoustic grating operating in a vertical plane.

In the vertically operating PAAG, a converter in the material, only longitudinal waves are created under the grate (figure 2). Since the source of these waves is the material surface, the transformation into a transverse wave occurs on it. In case of a plane-parallel object, it will occur during the first intermediate reflection from the bottom surface. Under equal conditions, longitudinal waves are less sensitive to small defects than transverse ones, they also they have the property of partial passing through closed planar defects and are weakly reflected from the right angle between the crack and the surface of the object. Therefore, this option is suitable to test coarse-grained materials only (e.g., austenitic steel) and only a direct beam without intermediate reflections. For the generation of flow shear waves in the design of the PAAG, a converter should be a plastic prism (figure 2). In this case, the angular limits of the beam oscillation in the prism are first and second critical angles that are set when configuring the instrument. Receiving echo signals of the grating also use the phase shift: the wave alternately rolled in all piezopolaron and the lattice, and the same delay lines allow you to fold the amplitude of the echo and to take this sum as the total amplitude of the reflection.

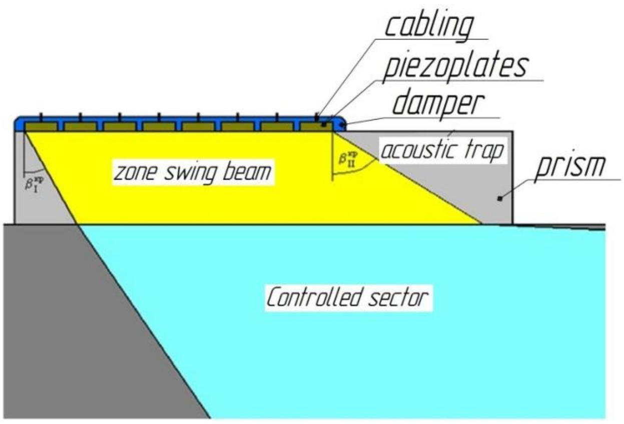

Figure 2. The scheme vertically current PAAG - converter.

In PAAG-detectors these processes occur at each value of the angle input and automatically modify with a very small step. The frequency change of the angle set by hardware is not greater than the frequency of the signal packages so that the pattern of the reflections generated on the screen of the device after accumulating and processing all the current data guaranteed the time to emerge at each angular value. Thus, the scan type "B" (profile) generated on the screen is a sector in which the sensitivity is the same in all directions, and the defects are represented as colored spots, approximate images. In these images, the color varies depending on the amplitude of the echo, and with the help of auxiliary devices (mouse, cursors, etc.) we can determine the numerical values of all required defect parameters (amplitude, coordinates, conditional height).

In the developed detector, AC signal phasing (automatic change of the azimuth) should be carried out not in vertical and horizontal planes, so as to excite lamb waves, the vertical angle of the ultrasound needs to be fixed, and automatic change should be subjected to the azimuth direction of the signal in the controlled plane of the sheet. However, note that technically this phase can be performed only within the angle from 0 to 90°. Therefore, the design of the PAAG, where a converter should consist of 4 gratings arranged in a square plane (figure 3), and built-in flaw in the program, respectively, to represent the image of a leaf with marks of detectable defects on the screen.

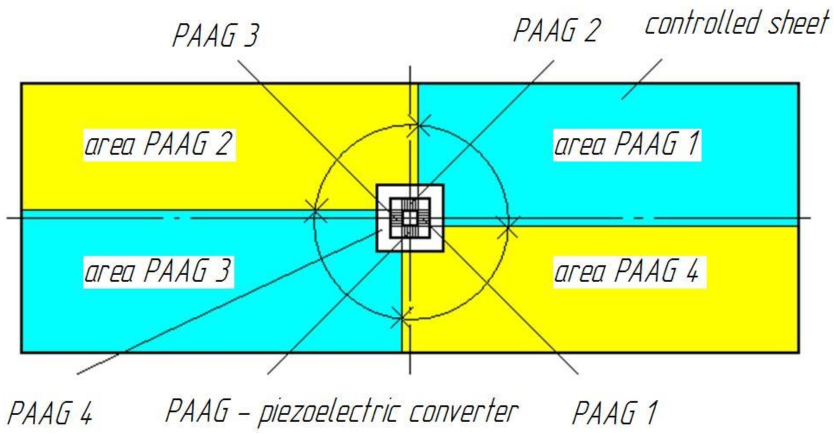

Figure 3. General scheme of an inspection of steel sheet PAAG - system.

Phase representation of signals in electronic circuits is performed using delay lines, a schematic diagram of which is shown in figure 4. Automatic change of the magnitude of the phase shift (delay signal) is achieved by simultaneous change of the potential resistance *Rф* or the capacitance of the S_F. The number of sections of delay line 1 is less than the number of phased array elements, as the first element of the PAAG receives a signal received at the input of the delay line, and the other receives it from the outputs of the respective sections.

The algorithm of automatic scanning that needs to be provided with specialized software PAAG flaw detector is shown in figure 5.

Software developers of the specialized PAAG -flaw detector must meet the following conditions:

- an image on the screen should be in the form of a rectangle that simulates the contours of the tested sheet;
- a label position sensor should be fixed in the center of the scan;
- a defect item should appear as a dark spot on the respective areas at a distance from the center corresponding in scale to the coordinates of the defect;
- when you hover the mouse over the image, the defect next to it should appear in the numerical parameters of reflection: the amplitude echo in decibels and the coordinates in degrees and millimeters relative to the installation point of the sensor.

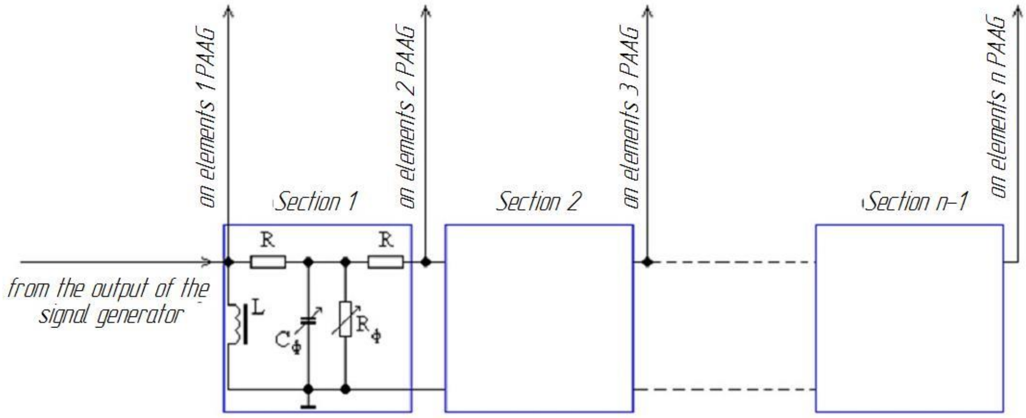

Figure 4. Schematic diagram of the delay line signal.

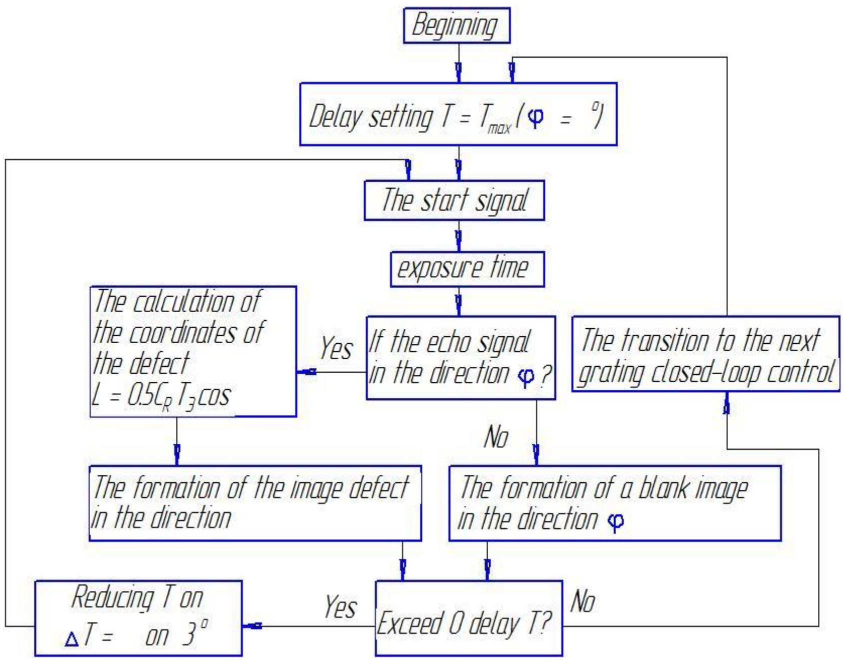

Figure 5. Algorithm auto scan.

An example of the intended image is shown in figure 6.

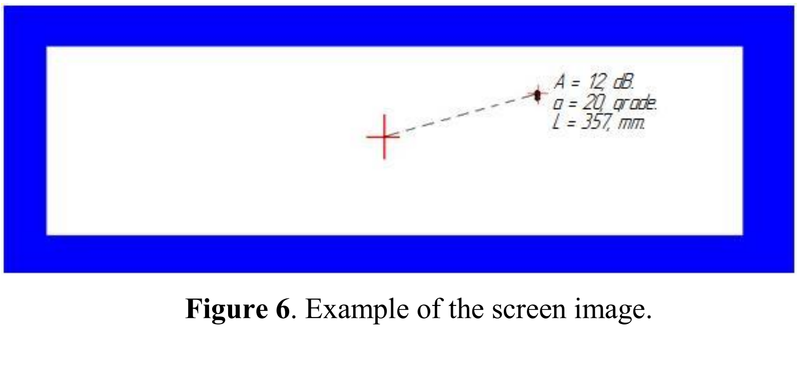

Figure 6. Example of the screen image.

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3. Conclusion
The developed specialized low-frequency flaw detector operating on PAAG will solve the problem of oil product leakage by providing early diagnosis during manufacturing and installation or operational defects of the bottom base metal sheets which are difficult to identify by conventional testing methods due to a large area of the object.

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