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# Hydroacoustic Rupture-Detection System for Major Underwater Pipelines

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**Abstract.** In modern conditions, a continuous monitoring system for major underwater pipelines is an essential part for maintenance of their normal operating. One of the possible approaches to the development of a continuous control system for the pipeline technical condition can be the method that is based on the luminal echo sounding. The work contains numerical experiments for the analysis of influence of leaks and ruptures of gas pipelines on the structure of the illuminated acoustic fields in conditions of natural stochasticity of water environment. In the quantitative experiment, the emitter was located on the axis of underwater acoustic channel (UAC). In this case, all the acoustic energy spreads along the UAC axis and there are no shade zones. As a result of the numeric experiments, correlations between the acoustic field distribution along the axis of underwater acoustic channel with and without gas pipeline ruptures at the range of 1 km and different levels of the random componentry were obtained. In the numeric experiment, the random componentry of the acoustic velocity field was discretely changing from 0,05 m/s to 0,5 m/s. The pipeline rupture was modelled at the ranges of 35; 70; 100 km. Pipeline rupture shifts the UAC axis; consequently, the acoustic field range rapidly drops at the depth of emitter. This effect is observed at all levels of the random componentry of the acoustic velocity field in the numeric experiments. Hydroacoustic leak-detection system for major gas pipelines is suggested based on the obtained results; it consists of the emitter and discrete receivers located along the UAC axis. The allocation precision is determined by the intervals between receiver along the UAC axis.

## 1. Introduction

Today there is a worldwide increasing demand for the offshore oil and gas development, which implies construction of major underwater pipelines for transporting crude hydrocarbons from recovery locations to processing plants, as well as the consecutive transportation from producers to consumers. Transportation of oil products via major pipelines is one of the most cost-effective methods. Lack of due control of underwater pipelines can lead to an industrial disaster. Oil spills at the Deepwater Horizon offshore drilling unit in the Gulf of Mexico is yet the brightest proof. This accident had negative ecological effects. BP spent approximately 50 billion USD for the oil spill remediation. Consequently, development of a reliable system for monitoring conditions of underwater pipelines at construction stage is a relevant topic for the research.



## 2. Topicality

Pipeline leaks lead to enormous financial losses for the industry and influence environmental situation; therefore, detection and allocation is the main problem. Currently, there are numerous methods for underwater pipeline control. The article [1] suggests the following solutions: acoustic sensors are mounted to both ends of a pipeline and leaks are detected via analysis of acoustic waves that propagate inside the pipeline. Early leak detection, in accordance with the article [2], is based on the correlational analysis of measured pressure and transported product delivery at the input and output points of a pipeline. Article-suggested experiments [3] demonstrate performance capabilities of passive acoustics for control of gas leaks of different levels. The article [4] describes new method for automatic detection of spills via interferometric side-scanning sonar mounted to the autonomous underwater vehicle. The article [5] suggests method of image smoothing that is based on mathematical morphology for improving underwater pipeline control via underwater recording. Use of underwater sensor networks has its disadvantages and in the article [6], it is suggested to fix the disadvantages with AUV. Article-suggested [7] continuous method for control of operable conditions of underwater pipeline uses optical emission as a sounding signal; optical emission is sent via at least one stationary measuring channel that is isolated from external environment; in order to create it, product pipeline is connected with optic waveguide continuously throughout the controlled section of a pipeline; leaks are detected if there is no signal at the output of stationary measuring channel and (or) signal at the input. Different from the previous method of product pipeline control, in the article [8], it is suggested to form sections with increased reflectivity at pre-set intervals – along the entire stretch of each optic waveguide; therefore, the breakages and their location can be detected by changes in parameters of reflected optical signal, which is being received from each high-reflectivity section; moreover, the sounding signal input and reception of reflected signals are conducted via registering optical reflectometer.

Constant monitoring of underwater pipelines requires reliable system, which does not require major financial investments and has minimal technical means. The hydroacoustic control system suggested in the article [9] meets these criteria; it is based on sounding along the pipeline with use of emitter and receiver, which are mounted at the borderlines of controlled pipeline section; thus, they form at least two trajectories of sounding beams. For example, one way is to emit the sounding signal from one point in various angular ranges, or from several points that vary in depth and (or) range with regard to receiver; thus, depth and arrival angle of corresponding sounding beams are recorded via vertical reception antenna system and then the data is compared with the earlier obtained checkpoint values of the vertical distribution of an acoustic field (VDAF) – changes in VDAF indicate the pipeline rupture. Another article-suggested system [10] consists of emitter that is mounted above the axis of the underwater acoustic channel (UAC) and reception systems that are located at borderlines between the lower and upper convergence zones; it is based on the analysis of VDAF function norms. Increase or decrease of VDAF function norm within one convergence zone indicates rupture. The next method used in the article [11], is based on the determination of local changes in water parameters at propagation path via analysis of VDAF function; the way it looks helps to determine changes in natural stochasticity of sound velocity field or its local abnormalities. Some of the methods suggested in articles [9-11] are collateral and are based on the VDAF function analysis.

Hydroacoustic systems of monitoring underwater pipelines with emitter positioned above or below the UAC axis have several disadvantages: for the full coverage of a pipeline it is necessary to use a few emitting and receiving systems that work in rotation; moreover, it is complex to implement the receiving equidistant vertical antenna grid and to mount it.

This work contains research on the perspective development of the hydroacoustic leak-detection system for major underwater pipelines that consists of emitting source and discrete receivers along the UAC axis.

The purpose of numerical experiment is to determine the functional connections of an acoustic field propagation along the UAC with various stochasticity levels of an acoustic velocity field with and without ruptures of a pipeline.

### 3. Description of the numerical experiment

The method of stochastic modeling of acoustic propagation in randomly inhomogeneous waveguides is applied during the conduct of the numerical experiments; the method is thoroughly described in the articles [10], [11]. In computational model, sound velocity was presented as follows:

$$C(x, z) = C_0(x, z) + \Delta C^{\approx}(x, z) + \Delta C^{\sim}(x, z),$$

where  $C_0(x, z)$  – the determined componentry of acoustic velocity field, which, in general, smoothly depends on both coordinates, and  $\Delta C^{\approx}(x, z)$  – the random componentry, with  $\langle \Delta C^{\approx}(x, z) \rangle = 0$ ,  $\Delta C^{\sim}(x, z)$  – the anthropogenic componentry of sound velocity, pipeline rupture.

Similar to the previously conducted and described [10] experiment, the initial data was selected for the current numeric experiment. The random componentry of acoustic velocity field  $\Delta C^{\approx}(x, z)$  was discretely changing from 0,05 to 0,5 m/s. A thousand (1000) of experiments was conducted for each value of  $\Delta C^{\approx}(x, z)$ . Flare angle of the emitting source equals  $\pm 5,7^\circ$ , which corresponds to the water propagation of beam trajectories without re-reflecting from the sea floor and surface of the model waveguide for all selected values of the random componentry of acoustic velocity field. Interval of averaging the field by depth is at  $z = \Delta z \cdot n$ ,  $\Delta z = 50$  м,  $n = 1 \div N = 40$ . The vertical profile is set at the range of 20-120 km with discretization range of 1 km. с дискретностью по дальности 1 км.

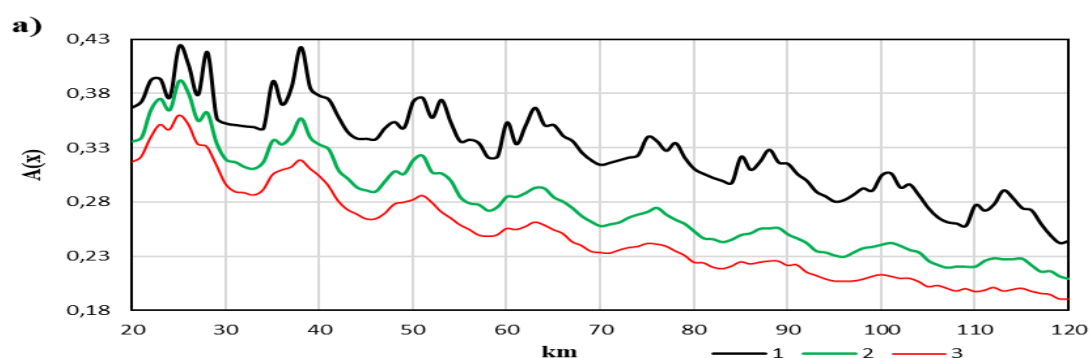
The initial data for the numerical modeling of underwater pipeline rupture are as follows: range from the illumination field emitter 35; 70; 100 km, random componentry of the acoustic velocity field  $\Delta C^{\approx}(x, z) = 0,05; 0,25; 0,5$  m/s, determined correcting factor that models rupture  $\Delta C^{\sim}(x, z) = -1000$  m/s; since gas acoustic velocity  $C_{\text{gas}} = 500$  m/s [12], in the bubble zone, with gas content in the water mix approximately equal to 0,03%, acoustic velocity in water drops to values around 500 m/s, rupture-modeling correcting factor gradually decreases to zero value closer to the sea surface, spill surface – is 500m at the surface; therefore, the rupture is modeled as an upside-down triangle with a peak the the rupture point.

The numeric experiments were conducted with use of software [13].

### 4. Results and discussion

The first part of the numeric experiment was to determine the influence of level  $\Delta C^{\approx}(x, z)$  on the acoustic field distribution along the UAC axis.

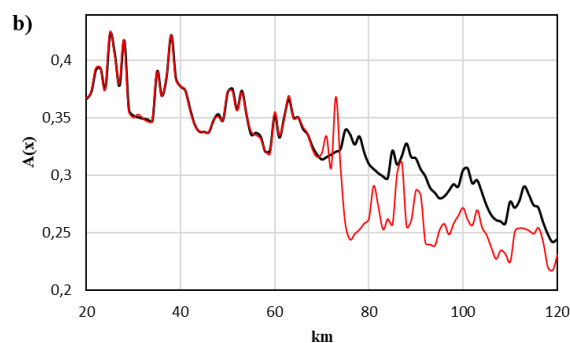
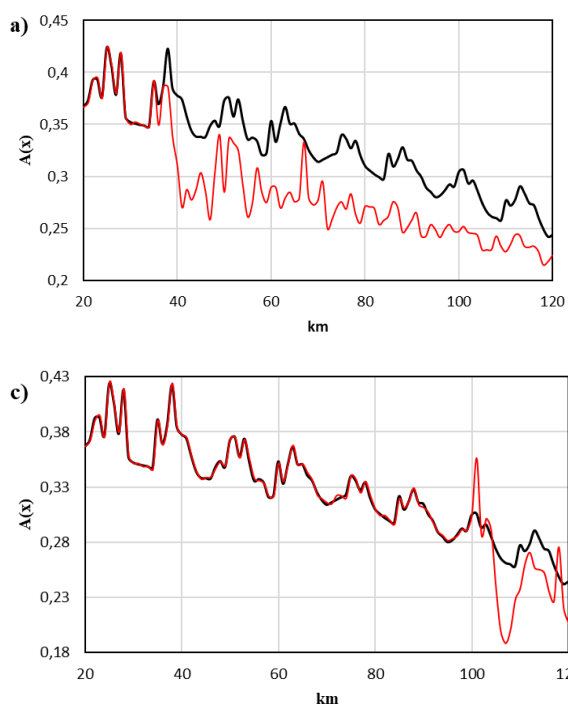
Acoustic field distributions along the UAC axis for  $\Delta C^{\approx}(x, z) = 0,05; 0,25; 0,5$  m/s are shown in Figure 1.



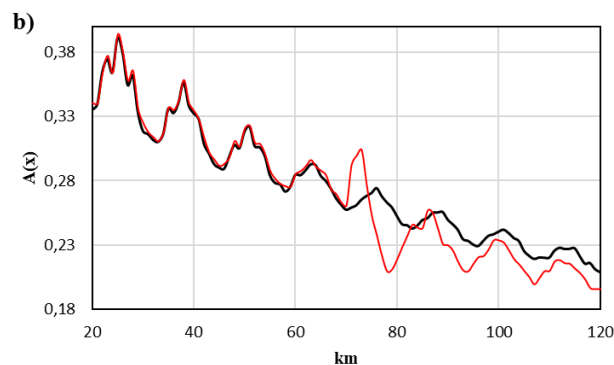
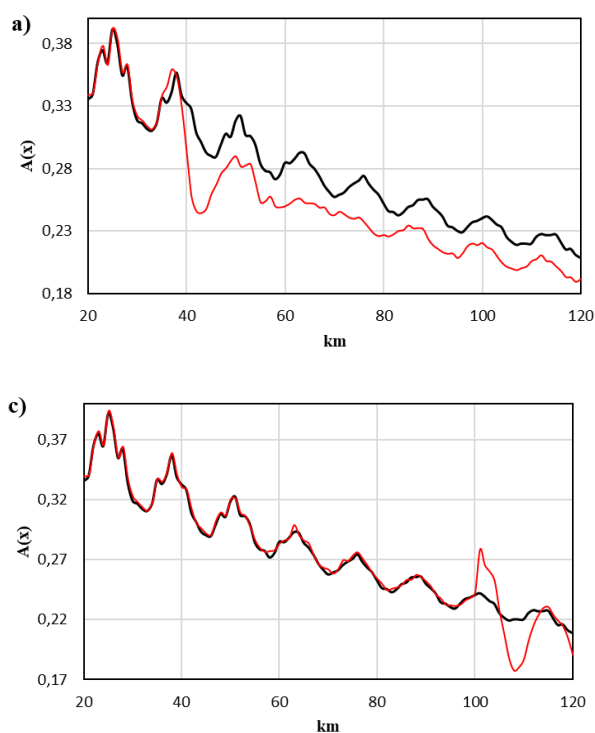
**Figure 1.** Acoustic field distribution along the axis of underwater acoustic channel. Levels of the random componentry vary. 1 -  $\Delta C^{\approx}(x, z) = 0,05$  m/s; 2 -  $\Delta C^{\approx}(x, z) = 0,35$  m/s; 3 -  $\Delta C^{\approx}(x, z) = 0,5$  m/s.  $A(x)$  – acoustic field distribution range.

As it follows from the numeric experiment, the acoustic field at the UAC axis has periodic character and with increase of the random componentry of the acoustic velocity field, its range decreases in a monotonous manner.

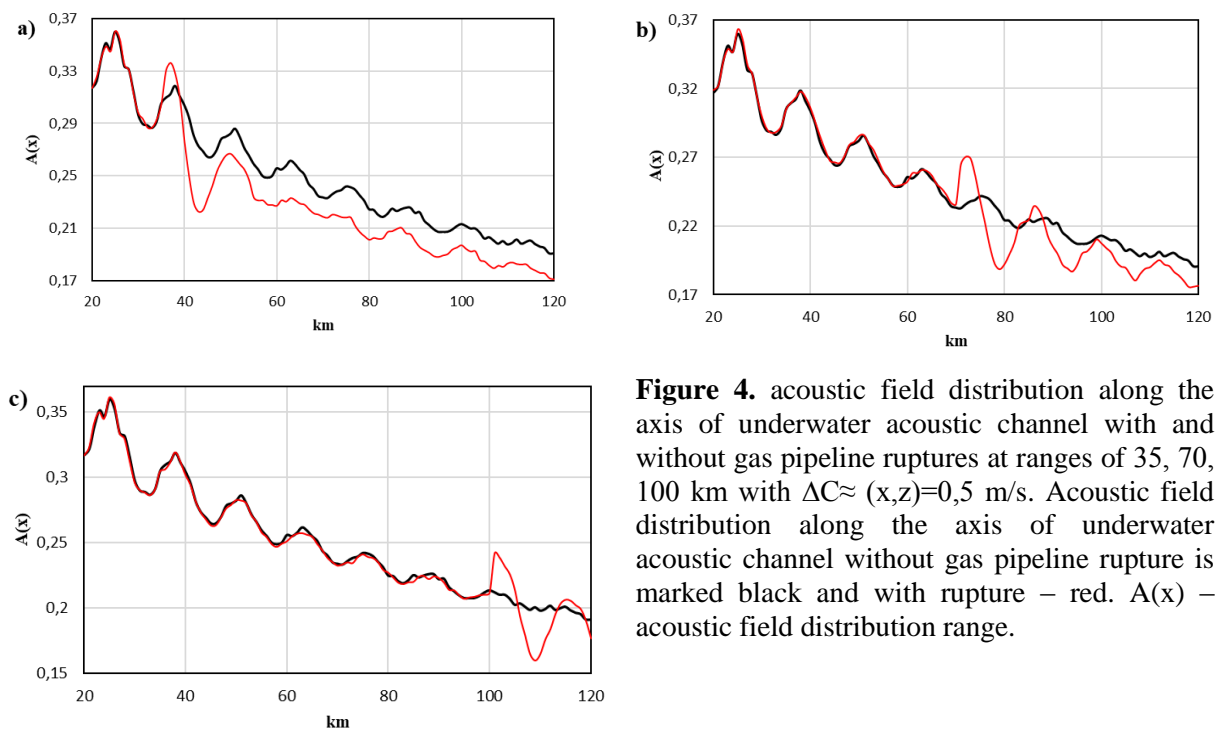
Figures 2-4 show the results of the numeric experiment on determining the informative indicators of pipeline ruptures with the fluctuating natural stochasticity parameters of the water environment.



**Figure 2.** acoustic field distribution along the axis of underwater acoustic channel with and without gas pipeline ruptures at ranges of 35, 70, 100 km with  $\Delta C \approx (x,z)=0,05$  m/s. Acoustic field distribution along the axis of underwater acoustic channel without gas pipeline rupture is marked black and with rupture – red.  $A(x)$  – acoustic field distribution range.



**Figure 3.** acoustic field distribution along the axis of underwater acoustic channel with and without gas pipeline ruptures at ranges of 35, 70, 100 km with  $\Delta C \approx (x,z)=0,35$  m/s. Acoustic field distribution along the axis of underwater acoustic channel without gas pipeline rupture is marked black and with rupture – red.  $A(x)$  – acoustic field distribution range.



**Figure 4.** acoustic field distribution along the axis of underwater acoustic channel with and without gas pipeline ruptures at ranges of 35, 70, 100 km with  $\Delta C \approx (x,z)=0,5$  m/s. Acoustic field distribution along the axis of underwater acoustic channel without gas pipeline rupture is marked black and with rupture – red.  $A(x)$  – acoustic field distribution range.

As it follows from the presented results, occurrence of rupture is characterized with rapid range drop of the acoustic field after the rupture coordinate. It is explained with shift of the UAC axis. This informative indicator can lay the foundation for the development of hydroacoustic system for early detection of underwater pipeline leaks.

## 5. Conclusions

In accordance with the numeric experiments, the structure for the hydroacoustic system for early detection of underwater pipeline leaks can be suggested; it contains the emitter and discrete receivers located along the UAC axis. Rapid drop at one of the receivers can indicate a leak with coordinates that are smaller than the receiver-coordinates; specification of coordinates is possible via searching means such as sector-scanning or side-scanning sonar, that are located at the pull-drawn underwater vehicle.

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