 https://doi.org/10.1051/e3sconf/201912702006

Complex for experimental research of elastic wave interactions with ice layer

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Abstract. An adjustable pneumatic generator of acoustic signals with shock excitation was developed. Measuring and computing complex was also created to investigate elastic acoustic wave propagation along ice surface. Experiments on low-frequency acoustic signal propagation from the pneumatic generator were carried out in «water-ice-air» system. The possibility to apply the developed measuring and computing complex for physical modeling of acoustic wave propagation from earthquake sources along ice cover was confirmed.

1 Introduction

The paper [1] experimentally proves that deformation-acoustic activity which appears before earthquakes may be considered as a complex precursor of a seismic event. One of the methods to record earthquake precursors is the method of acoustic elastic wave recording in the range from 0 to 10 kHz in small water pools [2-5].

In Arctic conditions, there is a necessity to record earthquake sources located under the ice far from coastline. Such a question statement requires recording of hydroacoustic waves taking into account their interactions with ice surface. The papers [6, 7] present mathematical models for acoustic signal propagation taking into account reflections at the boundary of two mediums. However, applicability of such models in practice requires additional investigation with consideration to real conditions.

The aim of the paper is the development of a measuring and computing complex to investigate the interactions of elastic waves with ice layer in real conditions.

In order to do that, we need to solve the following tasks: to develop instrumentation imitating earthquakes, to create a measuring and computing complex for investigation of acoustic wave propagation along an ice layer, to make experimental research of elastic wave propagation at the boundary of two mediums, «water-ice».

2 Materials and methods

2.1 Investigation methods

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Elastic wave propagation at the boundary of several mediums is a complex mathematical problem. At the present time, mathematical models for elastic wave propagation along ice cover of water mediums are being developed. One of the promising investigation directions is based on the application of directed Green's function method [6, 7]. However, such models lack the knowledge of initial conditions and real natural medium properties (ice) for practical applications. Thus, to obtain adequate results and to verify mathematical models, we need natural experimental researches.

2.2 Elastic wave generator

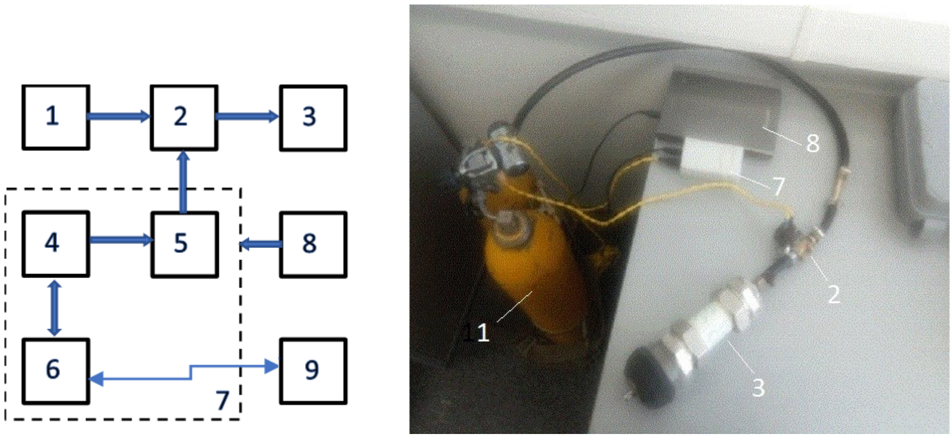
To generate an elastic wave in an ice layer, pulse powers of several kW are required. Generators of GP-24 type are capable of generating pulse shock waves of such power [8]. A significant disadvantage of such generators is large dimensions, weight and energy consumption. For example, application of GP-24 generator requires an energy source of 5 kW and the generator weight is 120 kg.

An air pneumatic generator can be used as a source of powerful shock wave [9]. The generator physical configuration is shown in Fig. 1. The generator operates from compressed air of several atmospheres in auto vibrating mode. When pressure reaches the critical value, air bursts from the generator interior for 100-200 ms with vibration frequency of 30-70 Hz. Such an air generator does not need an external power supply.

In order to investigate elastic wave propagation, we suggest providing the air generator with a system for interpulse period control.

Fig. 1. Pneumatic generator.

The control system (Fig. 2) should provide adjustment of pulse repetition rate from single to continuous with a defined interpulse period.



a) б)

Fig. 2. Complex of acoustic elastic wave generation:

a) functional scheme; б) physical configuration of the complex (without PC)

1 – compressed-air bottle; 2 – electromagnetic valve; 3 – pulse acoustic radiator of shock waves; 4 – microcontroller; 5 – executive unit; 6 – Bluetooth module; 7 – electromagnetic valve control device; 8 – battery; 9 – PC with Bluetooth module.

The complex for acoustic elastic wave generation operates as follows. The parameters, defining the duration and interpulse period at pneumatic generator 3 (PG) output, are uploaded to the microcontroller 4 via Bluetooth connection 6 by the help of a PC 9 and serial input interface. The microcontroller 4 forms pulses. During the time of their action, an electromagnetic valve 2 is opened by an executive unit 5 and the air from the bottle enters the pneumatic generator 3.

Pulse duration is chosen so that pressure reaches its critical value in the operating PG by the end of the pulse. When the pressure critical level is achieved, a part of the air is sharply blown out of the PG interior into the outer space. Airburst lasts for a short period of time of about 100-200 ms in attenuating oscillation mode with the frequency from 30 to 70 Hz. As the pulse stops, the electromagnetic valve is not affected any more, thus, air delivery to the PG is stopped and the process of acoustic pulse generation does not resume. When the next electromagnetic pulse comes, the electromagnetic valve is opened and the process of acoustic pulse formation is repeated. Adjusting the duration of the pause between the control pulses, we can regulate the acoustic signal radiation frequency.

2.3 Measuring and computing complex

A measuring and computing complex (MCC) was created for experimental check of pulse acoustic generator performance. Its functional scheme is illustrated in Fig. 3.

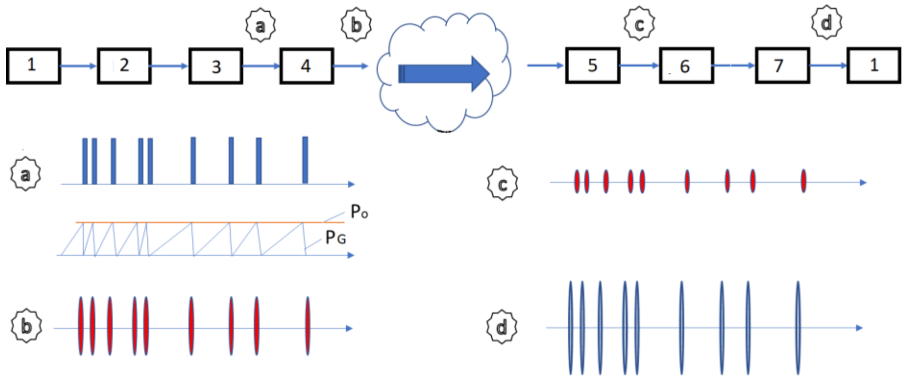


Fig. 3. Functional scheme of the measuring and computing complex:
1 – personal computer; 2 – microcontroller; 3 – control device; 4 – pneumatic generator 5 – hydrophone; 6 – hydrophone amplifier; 7 – analogue-to-digital converter.

The MCC operates as follows. The parameters, defining the pulse duration and the interpulse period are uploaded to the microcontroller 2 via Bluetooth connection by the help of a PC 1 and serial input-output interface. The microcontroller 2 defines the acoustic pulse repetition rate at PG 4 output though the electromagnetic valve control device 3.

The PG is descended at an appropriate depth though a hole made in the ice. A hydrophone 5 is descended through another hole at a defined distance from the PG. A gydroacoustic pulse is received by hydrophone 5, is amplified by hydrophone amplifier 6, is converted into a digital code via device 7 and enters PC 1 for processing and data display.

3 Results

Investigations were carried out in winter time during the following conditions: air temperature was minus 9ºC; wind velocity was not more than 5 m/s; ice thickness was 0,5m; water temperature was 1ºC; radiator depth was 1 m; hydrophone depth was 1 m; distance between the radiator and the hydrophone was 30 m; depth at the experimental area was 8 m; bottom was formed by sand, stones, water-inhabiting plants.

A pneumatic generator illustrated in Fig. 1 was used in the experiment. Pressure in the compressed-air bottle was 100 Pa. Pneumatic generator operation pressure was 10 Pa.

Signals were received by a omnidirectional hydrophone. The hydrophone is a piezoceramic spherical Ø 50 mm one. Its sensitivity is within the range of 20 - 2000 Hz – 180 µV/Pa ± 20%. The hydrophone capacity with the cable of 6 m is 34 nF ± 20%. The hydrophone physical configuration is shown in Fig. 4.
As a hydrophone amplifier we used a voltage one with the gain factor Gf = 200, input resistance R_{BX} = 10 mΩ and the pass band Δf = 2-4000 Hz at the level of -3 dB.
A multifunctional unit myDAQ (National Instruments) connected to a laptop was used as a recording unit for the signals received by the hydrophone. The signal sampling frequency was 10 kHz, ADC capacity was 16 binary digits. In order to shields from the air temperature change effect, the hydrophone amplifier, multifunctional unit myDAQ and the laptop were placed inside a building, where the temperature was within 15 ± 2ºC (Fig. 5). Specialized software in LabView environment was used for signal recording and further analysis.

Fig. 4. Hydrophone.

Fig.5. Physical configuration of the MCC.

Fig. 6 and 7 illustrate signal oscillograms recorded at the distance of 30 m from the radiator.

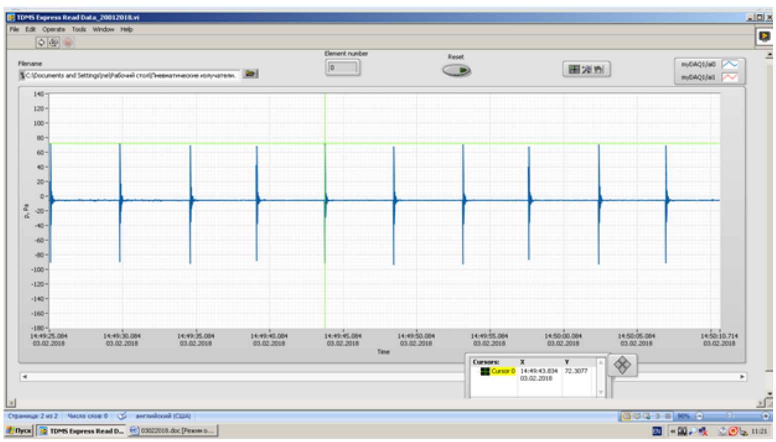


Fig. 6. Oscillogram of signal periodic sequence recorded at the distance of 30 m from the radiator within the interval from 14:49:25 till 14:50:10 of local time.

Fig. 7. Oscillogram of a single pulse recorded at the distance of 30 m from the radiator within the interval from 14:49:48.483 till 14:49:48.816 of local time.

Local time is along the horizontal axis, sound pressure in Pa is along the vertical axis. Middle line shift relatively the value 0 Pa is determined by the compensated shift of electronic tract zero level caused by air and water temperature effect. The maximum positive and negative components of pulses differ. The reduction of pulse negative components at the level of 60 Pa is clear. It is determined by the exceedance of hydrophone amplifier dynamic range.

Fig. 6 shows a signal received from the pneumatic generator at a distance of 30 m. The signal is a pulse sequence of relaxing oscillations with shock excitation and frequency filling. In this case, the pulse group repetition frequency is T = 0,2 Hz. The pneumatic generator control scheme allows us to receive shock acoustic waves with the repetition frequency from 2-3 Hz up to single pulses.

Fig. 7 presents a single signal (signal fragment in Fig. 6). Pulse group attenuation to the level of 0.1 from the maximum is about 100 ms. Total attenuation in a pulse group lasts for 300 ms. The period of attenuating oscillations in a pulse group is from 14 to 23 ms. The average frequency of attenuating oscillations in a pulse is f = 50 Hz.

4 Discussion

It was shown in the paper [1] that during earthquakes, sound and seismic signals of deformation nature have the pulse repletion frequency of T = 0,1-0,5 Hz in the background. The spectra of such signals is within f = 0-22 kHz. The highest amplitude of acoustic signal energy spectrum is observed at the frequencies of about f = 10-200 Hz.

Comparison of pneumatic generator sound signal parameters (T = 0-3 Hz, f = 50 Hz) with real earthquake sound signals (T = 0,1-0,5 Hz, f = 10-200 Hz) allows us to make a conclusion on the possibility to apply the suggested pneumatic generator for modeling of sound wave propagation processes in water mediums covered with ice.

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5 Conclusions

Experimental investigations of pneumatic generator showed the possibility to apply it for physical modeling of propagation of relaxation oscillations acoustic pulses with shock excitation and frequency filling in water mediums covered with ice.

The MCC based on the pneumatic generator will allow us to automate the experiments on the investigation of sound signal propagation from earthquakes in polar ice conditions.

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This research was funded by the National Key R&D Program of China (2018YFC1405900)