

Unbalanced rock mass vibration generator and its bench testing

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Abstract. This work presents an unbalanced borehole vibration source with the pneumatic actuator to affect the rock mass bottomhole zone in the seismic frequency range. The modulus-type source consists of the vibration generator with automatic step regulation of static moment, clamping node and built-in pneumatic device to transfer equipment in uncased boreholes. There are test results on the source prototype, amplitude and frequency characteristics and spectral content of the source signal.

1. Introduction

Seismic impact on rock mass is used to increase permeability and fluid flow in rocks by low-frequency elastic vibration treatment. The main object of the seismic impact for borehole oil and gas production technologies, coal bed degassing and nonferrous metal in-situ leaching is a bottomhole area of producing wells. The area hydrodynamic properties affect production capacity of the wells. One of the main factors of successful production is specific capacity of seismic emission dependent on the source type and its properties.

Experimental investigations prove that in order to increase gas and water permeability of a bottomhole area, impact frequency has to range from 100 to 300 Hz, intensity—not less than 0.01 W/m², duration—from 4 hours and more [1–4]. Numerical studies of near zone of different source emission [5–7] shows that the required values of the mentioned parameters are ensure by an unbalanced seismic source (unbalanced vibration generator) with the force 10–20 kN and higher [5]. Design of the source and results of its tests in soil and hard rocks are given below.

2. Unbalanced borehole source

The source contains unbalanced type generator of elastic oscillations 1 with a pneumatic actuator and electromechanical pressure device 2 (Figure 1). The source is capable of working along with the pneumatic device used for the transportation of equipment in a borehole [8]. Other facilities are remote control, air supply hoses, conducting wire, frequency counter and geophone set next to the borehole collar. The geophone is employed to control the source operation.



Figure 1. Borehole vibration generator.



In the transportation mode pressurized air is supplied into the pneumatic device which transfers the equipment into the depth of the borehole [8]. In case of seismic impact pressurized air enters the pneumatic actuator input, and it is discharged into the atmosphere through the output. Vibration frequency is regulated by the frequency counter data. Signals of geophone, registering rock displacements, are transmitted to the counter input. Frequency control is accomplished due to the regulation of pressure and air supply.

2.1. Pneumatic actuator

We have chosen a type and power of a pneumatic actuator of the unbalanced generator on the basis of seismic impact intensity equal to 0.01 W/m^2 . If the radius of vibration impact is limited to 10 m, then, the seismic emission intensity has to be not less than 12 W. At the same time it is a well-known fact that in rock masses energy conversion coefficient of seismic transmitters does not exceed 5–10% [9]. To obtain the required seismic energy the actual power has to be not less than 120–240 W. In the limited space of a borehole this power is provided by volumetric pneumatic actuator made in accordance with high-technology pneumatic motors with 40–50% energy conversion efficiency. The unbalanced generator is embedded with PHR motor (Ober, Italy) with the following parameters: up to 570 W of output power, 316 r/sec of maximum rotation speed without loading, 183 r/sec of maximum rotation speed if power is 570 W, up to 13.8 l/sec of gas supply (input discharge) in normal conditions and 0.62 MPa pressure, 0.8 N·m of torque, 1.1 kg mass and 50 mm diameter.

The air hose provides the required pressure and air supply into a pneumatic motor. To calculate a diameter of air hose flow section d we use Weymouth formula for simple gas pipeline [10]

$$d = \left[\frac{a \cdot V^2 \cdot \rho_a^2 \cdot z \cdot R_a \cdot T \cdot L}{P_1^2 - P_2^2} \right]^{3/16}, \quad (1)$$

where V —volume air discharge, m^3/sec ; T —its temperature, $^\circ\text{K}$; ρ_a —density, kg/m^3 in normal conditions, P_1 , P_2 —pressure at the air hose input and output, respectively, Pa; $z = 0.93$ —compression coefficient; $a = 0.01525 \text{ m}^{1/3}$; $R_a = 287 \text{ J/(kg} \cdot \text{K)}$ —gas constant of air. To reach limiting operating characteristics of PHR motor with 50–150 m long hoses their diameter is to be not less than 11–13 mm. In the experimental sample of the tool we use 50 m long hoses with 15 mm flow section.

2.2. Unbalanced generator

Amplitude of vibration generator action force F depends on unbalanced mass rotation

$$F = m \cdot r \cdot (2\pi f)^2, \quad (2)$$

where m —unbalanced mass, m ; r —its eccentricity, m ; f —unbalanced mass rotation frequency (seismic vibrations frequency), Hz . It is necessary to regulate kinetic momentum of unbalanced vibrator mr to gain the preferable amplitude–frequency characteristics of the action force in 100–300 Hz frequency range. However, due to the limit of loading on bearing units and walls of an uncased borehole the action force maximum value in the developed source is limited to 15 kN. So, if the kinetic momentum of the unbalanced generator is not regulated, then, in case of vibration frequency drop from 300 to 100 Hz and in accordance with (2), the action force amplitude decreases by 9 times. It causes intensity drop below the permissible limit and reduction of the source frequency range amplitude. To solve the problem the vibration generator is based on the scheme of two unbalanced masses. One of the masses m_1 has constant eccentricity r_1 , another one has m_2 which is $m_2 < m_1$, and its eccentricity may vary from r_2 to r_3 (Figure 2). Unbalanced mass gradual displacement along the borehole axis is caused by inertia force at the frequency f_i . It happens when the inertia force is superior to adhesive force $Fr(f_i)$ of m_2 unbalanced mass with the axis on which the mass is fixed.

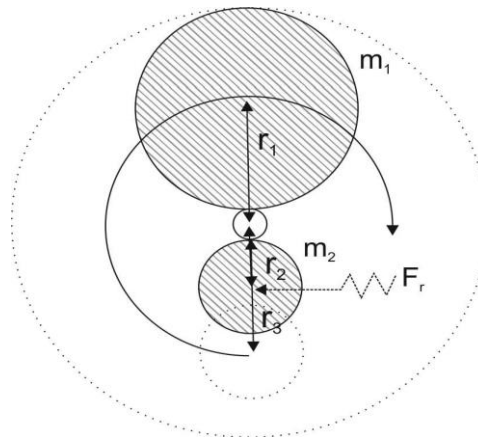


Figure 2. Scheme of a borehole vibration source vibration generator: m_1 —main unbalanced mass; m_2 —auxiliary unbalanced mass.

2.3. Pressure device

Pressure device is an obligatory part of a vibration source. It provides contact with the borehole walls and transmission of seismic vibrations to rock mass. Pressure device has to exceed the rated value of uncased borehole diameter by at least two times as in coal beds uncased boreholes diameter deviates from the design value. According to the work [11] a horizontal degassing borehole drilled with 98 mm diameter have a different operating diameter. It varies from 84 to 180 mm and varies greatly in all the parts of the borehole, especially at 10–20 m from the borehole collar. That is why anchor systems with small diameter margin such as wedge-like mechanisms are not applicable. The lever pressure device in the developed source is similar to the devices used in seismic tools for vertical seismic profile shooting of boreholes. The pressure device contains reversible DC motor. Through a multiphase planetary reduction gearbox and screw drive its rotation transforms into action of the lever, which moves forward and presses the vibration source to a borehole wall. Supply voltage of the pressure device is 24 V, current is not more than 1.5 A. The device can work in boreholes up to 240 mm in diameter. Control of the pressing force is done in accordance with ampere meter data from the remote control.

The main properties of the developed seismic impact facility:

- work in uncased 89–122 mm diameter boreholes with its tilting angle from -90° to +90°;
- maximum diameter of boreholes 240 mm;
- action force amplitude up to 15 kN;
- impact frequency in hard rocks not less than 150 Hz;
- air pressure up to 0.8 MPa;
- air supply up to 13.8 l/sec;
- vibro seismic module length 1430 mm;
- 16 kg mass.

3. Unbalanced source test

Testing has been carried out in loamy soil and solid hard rocks. In the first case the source has been placed at a depth of 3 m in a vertical uncased borehole 180 mm in diameter. The borehole is drilled in near-surface layer of mellow loam soil with the density of 1300 kg/m³ density. In the series of experiments it is proved that a seismic P-wave velocity (V_p) in near-surface layer is 300 m/sec, in underlying soil—1350 m/sec. Seismic vibrations registration is performed by geophones GS20-DX (LLC OJIO-Geo limited, Oktyabrsk) set along the linear profile 145 m long at a step of 5 m. The signals are registered with the help of equipment ROSA-A (Siberian Research Institute of Geology, Geophysics and Mineral Resources, Novosibirsk). Air pressure in a pneumatic actuator of the source is changed from 0.4 to 0.7 MPa. We obtain that frequency of the first harmonic of seismic oscillations in soil depends on air pressure in the pneumatic actuator. The frequency is 35–36 Hz at the air pressure

of 0.7 MPa, 30–31 Hz at 0.6 MPa and 24–26 Hz at 0.4–0.5 MPa. In the experimental conditions the actuator power is not sufficient to cause rotation of the generator unbalanced masses to the frequency more than 36 r/sec. The main reason is high reactive loading of the vibration source in the described medium [12].

Figure 3 shows the seismic energy flow spectra at several observation points at air pressure in pneumatic actuator of 0.7 MPa. Energy flow (seismic impact intensity) is estimated by the formula

$$\Phi = \frac{1}{2} \rho \cdot V_p \cdot (X_0')^2, \quad (3)$$

where X_0' —velocity amplitude of rock displacement in vibration field. Value X_0' is calculated by the geophone output signals using the technique presented in the work [13].

The presented graphs show that the intensity of seismic impact drops fast in case of far distance from the source. Seismic energy flow at the basic oscillations mode decreases by 2 times with the distance increase from 1 to 5 m (Figures 3a and 3b).

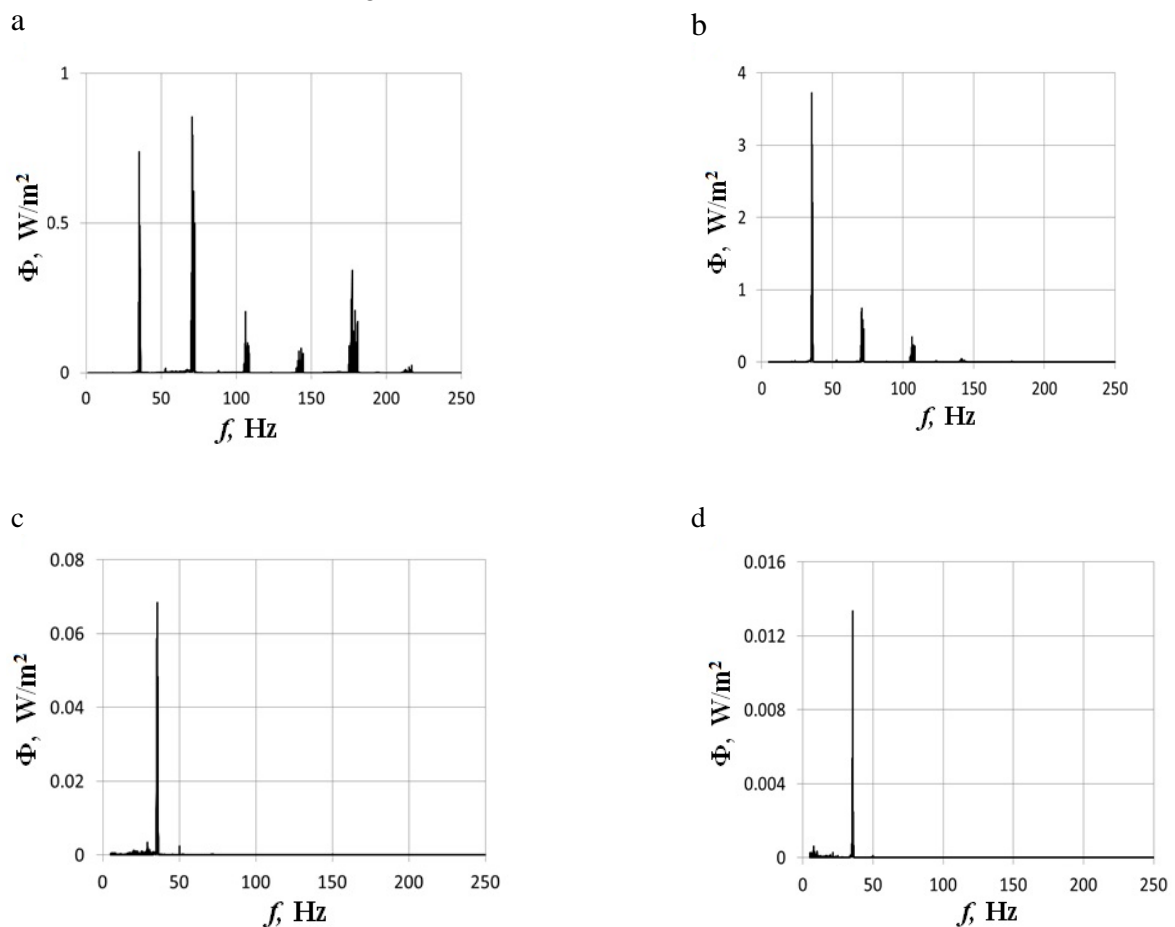


Figure 3. Seismic energy flow spectrum (seismic impact intensity) at various distances r from the source if the air pressure is 0.7 MPa: (a) $r = 1$ m, (b) $r = 5$ m, (c) $r = 30$ m, (d) $r = 65$ m.

The upper harmonic of oscillations decreases stronger, at the distance of 20–30 m they are negligibly small (Figures 3c and 3d). Compound flow of seismic energy in soils at the frequency of 250 Hz at the distance of 1 m from the source is equal to 8.8 W/m^2 , at 5 m— 0.033 W/m^2 , at 30 m— 0.46 W/m^2 . The radius of the vibration impact with the intensity higher than 0.01 W/m^2 is approximately 7 m. Taking into account basic vibration mode of 35–36 Hz frequency, the source impact radius does not exceed 3–4 m.

The source tests in solid rocks have been conducted in horizontal uncased boreholes with the diameter of 105 mm drilled in a pit wall. For the experiments pressure at the pneumatic actuator input has been changed from 0.6 to 0.8 MPa. Figure 4 shows the geophone output signal and amplitude spectrum of vibrations of bottomhole rock at a distance of 0.5 m from the source and at the actuator air pressure of 0.8 MPa.

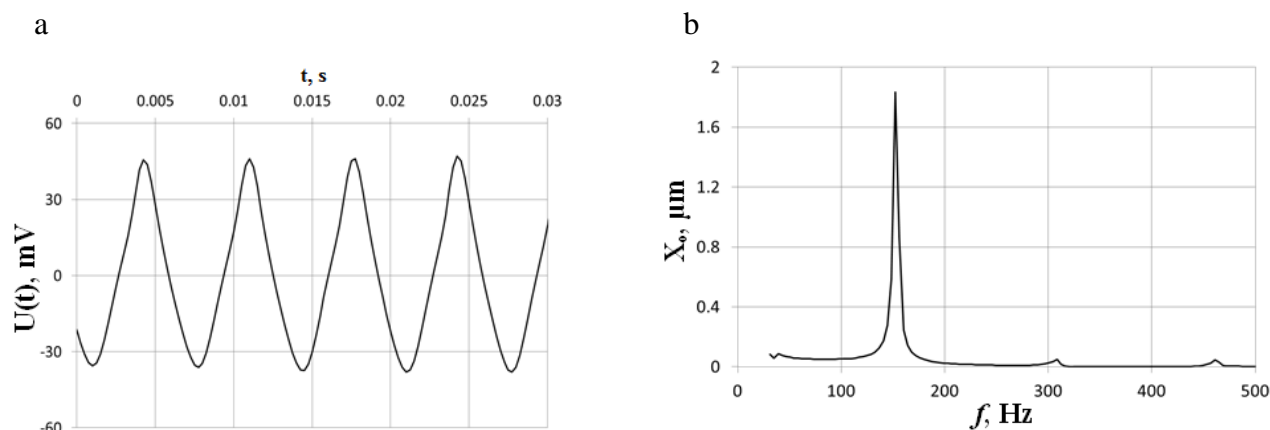


Figure 4. (a) Output signal of geophone and (b) and amplitude spectrum displacement of bottomhole rock mass in seismic field ($r = 0.5$ m).

The signal is similar to a sine wave (Figure 4a). Amplitudes of the second and third harmonics of seismic oscillations do not exceed the main mode of 152–156 Hz frequency (Figure 4b). Seismic energy flow in this frequency line is 19.2 W/m^2 at the observing point. The impact with the intensity more than 0.01 W/m has the radius of as 12 m.

4. Conclusion

The developed seismic source with a pneumatic actuator, electromechanical pressure device and unbalanced generator with automatic regulation of the kinetic momentum provides seismic impact on incased boreholes up to 240 mm in diameter with the action force amplitude up to 15 kN.

The source contributes to seismic impact on bottomhole of solid rock masses in a harmonic mode with the frequency up to 150–160 Hz and intensity more than 0.01 W/m^2 at the distance up to 12 m from the source.

In soft soils the source emits seismic signal the spectrum of which is rich with intensive upper harmonics. Due to the harmonics range of multifrequency processing of rock mass bottomhole at the distance of 3–4 m is widened up to 110–180 Hz. The radius of the basic mode vibrations impact on soils is 7 m with the frequency of 30–40 Hz and intensity more than 0.01 W/m^2 .

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