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Reduction of auto seismic oscillations of the ballistic laser gravimeter on account of the excitation of the induction-dynamic catapult by a pulse packet

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Abstract

In order to reduce auto seismic oscillations in the ballistic laser gravimeters (BLG) with a symmetric method of measuring the gravitational acceleration (GA), an induction-dynamic catapult (IDC) is used, which is excited by a pulse packet from a capacitive energy storage unit (CES). With such excitation, a decrease in the amplitude of auto seismic oscillations is achieved by reducing the amplitude and increasing the duration of action of the electrodynamic force that occurs in the IDC when pushing the test body (TB).

A mathematical model of the IDC of the ballistic laser gravimeter with a symmetric method of measuring the GA is developed and the modeling of its electromechanical characteristics is carried out. Various methods of generating a packet of excitation pulses of the IDC inductor are considered and the characteristics of electrodynamic force pulses that accelerate the armature of the catapult with TB are investigated for them. The effect of IDC excitation by a pulse packet on the auto seismic component of the GA measurement is investigated. It is shown that on account of the excitation of the IDC by a ten-pulse packet, the auto seismic component of the uncertainty of the GA measurement by ballistic gravimeters can be reduced several (3–5) times in comparison with the excitation of the catapult by a single pulse.

Keywords: ballistic laser gravimeter; induction-dynamic catapult; auto seismic component of measurement uncertainty.

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Introduction

For high-precision measurements of the absolute value of the gravitational acceleration g, the ballistic laser gravimeters (BLG) are used, in which a test body (TB) is pushed, which is an integral part of the Michelson laser interferometer measuring system [1–4]. The BLG measures the path and time intervals of the TB during its free movement in the vacuum chamber of the gravimeter [1]. Two types of gravimeters with free movement of the TB in a gravitational field are used, which implement symmetric and asymmetric methods of measuring g. In the symmetric method, the measurement of g is performed on both the upward and downward branches of the TB trajectory, and in the asymmetric method – only on the downward one. BLGs with a symmetric measurement scheme have a number of advantages. Since the resistance forces of the gaseous medium affect the measurement result with opposite signs during the rise and fall of the TB, there is a mutual compensation. In addition, there is no problem of raising the TB to the starting position, as in a gravimeter with an asymmetric measurement scheme [5, 6]. The main disadvantage of a BLG with a symmetrical measurement scheme of g is the mechanical impact that acts when pushing the TB by catapult. At this, auto seismic oscillations of the foundation and all mechanical elements of the gravimeter occur, which cause the corresponding component of the measurement uncertainty g [7, 8].

Analysis of literature data and problem statement

In a BLG with electromagnetic catapult, the indirect conversion of the CES electrical energy into vertical pushing of the TB is performed [6]. The pushing device is made on the basis of a symmetrical six-bar lever mechanism (pantograph) with a central axis fixed in the vacuum chamber of the ballistic unit. The central axis is connected to the ferromagnetic armature of the catapult. When the electromagnet winding is excited by CES, a current pulse occurs and due to the magnetic field, a massive ferromagnetic armature is drawn into the inner cavity. Moving vertically down, the ferromagnetic armature pulls the pantograph, which by increasing the axial dimensions pushes the carriage with the TB vertically upward with subsequent capture.

This multi-stage conversion of the CES electrical energy into mechanical energy of the TB vertical motion is accompanied by friction and subsequent wear of the contacts of moving elements, vibration and shock in the connecting elements, damping of the part of energy, bending and deformation processes, etc.

In order to eliminate these components of the measurement uncertainty, it is proposed to use a BLG with an induction-dynamic catapult (IDC), which provides direct electromechanical energy conversion and allows to adjust easily the height of the TB pushing [9].

When the CES discharges on the inductor winding (IW), there is a current pulse, under the action of which the magnetic field directs current in the conductive armature (CA). Under the action of axial electrodynamic force (EDF) f_z, the repulsion of the CA together with the TB performs free vertical movement ΔZ. At this, the receiving and emitting device activates and the measurement of g is performed. The short and significant amplitude EDF pulse between the IW and the CA of the catapult causes significant auto seismic oscillations of the BLG foundation, which affect the measurement of g. These oscillations can be reduced by increasing the duration and reducing the amplitude of the EDF between the IW and the CA by creating a packet of short power pulses of reduced amplitudes. The duration of the packet is determined by the period of propagation of the pulses generated at the excitation of the IDC from the CES sections.

The purpose of the study

The purpose of the study is to analyze the effect of the parameters of the excitation pulse packet of the IDC inductor on the EDF characteristics, which determine the magnitude of the auto seismic component of the uncertainty of the GA measurement.

Mathematical model of the BLG catapult

Let's consider the main processes in the IDC, which pushes the TB vertically upward. To solve this problem we use an approach based on the calculation of interconnected electromagnetic and mechanical processes [10].

In the catapult under consideration, when the IW with inductance L_1 and active resistance R_1 is connected to the CES, a current i_1 flows, which generates a magnetic field that induces current i_2 in the CA with inductance L_2 and active resistance R_2. On the account of EDF, the CA is pushed along the z axis with a speed v_z.

Initial conditions of the mathematical model:
$i_n(0) = 0$ – the current of the n-th element (1 – IW, 2 – CA);
$h_z(0) = 1\,\text{mm}$ – the initial axial shift of n-th elements;
$u(0) = U_0$ – the CES voltage with capacitance C_0;
$v_z(0) = 0$ – the velocity of the CA with the TB.

The solution of equations describing electrical, magnetic and mechanical processes is given in recurrent form [10]. Electrical processes in the IDC active elements are described by a system of equations [11]:

$$R_1 i_1 + L_1\frac{di_1}{dt} + \frac{1}{C_0}\int_0^t i_1 dt + M_{12}(z)\frac{di_2}{dt} + \\ + v_z(t) i_2 \frac{dM_{12}}{dz} = 0, \quad \frac{1}{C_0}\int_0^t i_1 dt = U_0, \tag{1}$$

$$R_2 i_2 + L_2\frac{di_2}{dt} + M_{21}(z)\frac{di_1}{dt} + i_1 v_z(t)\frac{dM_{21}}{dz} = 0, \tag{2}$$

where $M_{12}=M_{21}$ is the mutual inductance between the IW and the CA.

The system of equations (1) – (2) is reduced to the following equation:

$$a_3\frac{d^3 i_1}{dt^3} + a_2\frac{d^2 i_1}{dt^2} + a_1\frac{di_1}{dt} + a_0 i_1 = 0, \tag{3}$$

where $a_3 = \upsilon$; $a_2 = \chi - 2Mv_z\frac{dM_{12}}{dz}$;

$a_1 = R_1R_2 + \frac{L_2}{C_0} - v_z^2\left(\frac{dM_{12}}{dz}\right)^2$; $a_0 = \frac{R_2}{C_0}$; $\upsilon = L_1L_2 - M_{12}^2$;

$\chi = R_1L_2 + L_1R_2$.

The characteristic equation of differential equation (3) has the form [12]:

$$x^3 + r_* x^2 + s_* x + t_* = 0, \tag{4}$$

where $r_* = a_2/a_3$; $s_* = a_1/a_3$; $t_* = a_0/a_3$.

When substituting $y = x + r_*/3$, equation (4) is reduced to the form:

$$y^3 + p_* y + q_* = 0, \tag{5}$$

where $p_* = s_* - r_*^2/3$; $q_* = 2\left(r_*/3\right)^3 - r_* s_*/3 + t_*$.

The roots of equation (5) are found using the Cardano formula:

$$y_1 = u_* + v_*;\quad y_2 = \varepsilon_1 u_* + \varepsilon_2 v_*;\quad y_3 = \varepsilon_2 u_* + \varepsilon_1 v_*, \tag{6}$$

where $u_* = \sqrt[3]{D^{0,5} - 0,5q_*}$; $v_* = \sqrt[3]{-D^{0,5} - 0,5q_*}$;

$\varepsilon_{1,2} = 0,5\left(-1 \pm j\sqrt{3}\right)$; $D = \left(p_*/3\right)^3 + \left(q_*/2\right)^2$ – discriminant of equation (5).

If $D < 0$, then after a series of transformations we obtain the expression for currents:

$$i_n(t_{k+1}) = \delta^{-1}\left\{\left[i_n(t_k) - \frac{i_m(t_k)v_z^2}{R_1R_2}\left(\frac{dM_{12}}{dz}\right)^2\right]\left(\alpha_1\beta_2\beta_3 + \alpha_2\beta_1\beta_3 + \alpha_3\beta_1\beta_2\right) + \left(\Omega_n - \frac{v_z\Omega_m}{R_n}\frac{dM_{12}}{dz}\right)\left[\alpha_1\left(\beta_2+\beta_3\right) + \right.\right.$$

$$\left.\left. + \alpha_2\left(\beta_1+\beta_3\right) + \alpha_3\left(\beta_1+\beta_2\right)\right] + \left(\Lambda_n - \frac{v_z\Lambda_m}{R_n}\frac{dM_{12}}{dz}\right)\left(\alpha_1+\alpha_2+\alpha_3\right)\right\}\left[1 - \frac{v_z^2}{R_1R_2}\left(\frac{dM_{12}}{dz}\right)^2\right]^{-1}, \tag{7}$$

where $m = 1, 2$ at $n = 2, 1$;

$$\delta = \beta_1\beta_2\left(\beta_2-\beta_1\right) + \beta_1\beta_3\left(\beta_1-\beta_3\right) + \beta_2\beta_3\left(\beta_3-\beta_2\right);$$

$$\Omega_n = B_n + \frac{B_m v_z}{R_n}\frac{dM_{12}}{dz}; \quad \Delta t = t_{k+1} - t_k; \quad \Lambda_n = E_n + \frac{E_m v_z}{R_n}\frac{dM_{12}}{dz};$$

$$\alpha_1 = \left(\beta_3-\beta_2\right)\exp(\beta_1\Delta t); \quad \alpha_2 = \left(\beta_1-\beta_3\right)\exp(\beta_2\Delta t); \quad \alpha_3 = \left(\beta_2-\beta_1\right)\exp(\beta_3\Delta t);$$

$$\beta_p = \left\{2\left(a_2^2 - 3a_1a_3\right)^{0,5}\cos\left[2\pi\left(p-1\right)/3 + \varsigma\right] - a_2\right\}/3a_3;$$

$$\varsigma = \arccos\left[\left(a_2^2 - 3a_1a_3\right)^{-1,5}\left(4,5a_1a_2a_3 - a_2^3 - 13,5a_0a_3^2\right)\right]; \quad \gamma_1 = L_2; \ \gamma_2 = -M_{12};$$

$$B_n = \upsilon^{-1}\left[i_n(t_k)\left(M_{12}v_z\frac{dM_{12}}{dz} - R_nL_m\right) + i_m(t_k)\left(R_mM_{12} - L_mv_z\frac{dM_{12}}{dz}\right) - \gamma_k u_c(t_k)\right];$$

$$E_1 = \upsilon^{-2}\left\{i_1(t_k)\left[R_1\left(R_2M_{12}^2 + R_1L_2^2 - C^{-1}L_2\upsilon\right) - v_zM_{12}\frac{dM_{12}}{dz}\left(\chi + 2R_1L_2\right) + v_z^2\left(L_1L_2 + M_{12}^2\right)\left(\frac{dM_{12}}{dz}\right)^2\right] + i_2(t_k)\times\right.$$

$$\left.\times\left[v_z\left(L_2\chi + 2R_2M_{12}^2\right)\frac{dM_{12}}{dz} - M_{12}R_2\chi - V^2M_{12}L_2\left(\frac{dM_{12}}{dz}\right)^2\right] + u_c(t_k)\left(R_2M_{12}^2 + L_2^2R_1 - 2L_2VM_{12}\frac{dM_{12}}{dz}\right)\right\};$$

$$E_2 = \upsilon^{-2}\left\{i_1(t_k)\left[M_{12}\left(C^{-1}\upsilon - R_1\chi\right) + v_z\left(2R_1M_{12}^2 + L_1\chi\right)\frac{dM_{12}}{dz} - 2v_z^2L_1M_{12}\left(\frac{dM_{12}}{dz}\right)^2\right] + i_2(t_k)\left[R_2\left(R_1M_{12}^2 + R_2L_1^2\right) - \right.\right.$$

$$\left.\left. - M_{12}v_z\left(2L_1R_2 + \chi\right)\frac{dM_{12}}{dz} + \left(L_1L_2 + M_{12}^2\right)v_z^2\left(\frac{dM_{12}}{dz}\right)^2\right] + u_c(t_k)\left[v_z\left(L_1L_2 + M_{12}^2\right)\frac{dM_{12}}{dz} - M_{12}\chi\right]\right\},$$

where $u_c(t_k)$ is the CES voltage at the point of time t_k.

If the discriminant of the characteristic equation (5) $D > 0$, then after a series of transformations we obtain the expression for currents:

$$i_n(t_{k+1}) = \left(\xi_n - \frac{\xi_m v_z}{R_n}\frac{dM_{12}}{dz}\right)\Bigg/\left[1 - \frac{v_z^2}{R_1R_2}\left(\frac{dM_{12}}{dz}\right)^2\right], \tag{8}$$

where

$$\xi_n = g^{-1}\left[g^2 + \left(f-d\right)^2\right]^{-1}\left\langle g\cdot\exp(d\Delta t)\left[\left(g^2+f^2\right)\Theta_n - 2f\Omega_n + \Lambda_n\right] + \exp(f\Delta t)\left\{\sin(g\Delta t)d\left(f^2 - g^2 - fd\right)\Theta_n + \right.\right.$$

$$\left.\left. + \left(g^2 + d^2 - f^2\right)\Omega_n + \left(f-d\right)\Lambda_n\right] + g\cdot\cos(g\Delta t)\left[d\left(d-2f\right)\Theta_n + 2f\Omega_n - \Lambda_n\right]\right\}\right\rangle; \ \Theta_n = i_n(t_k) + \frac{v_zi_m(t_k)}{R_n}\frac{dM_{12}}{dz}.$$

Axial displacement of the armature with the TB occurs under the action of EDF:

$$f_z = i_1(t_k)i_2(t_k)\frac{dM_{12}}{dz}(z). \tag{9}$$

The value of the vertical displacement of the armature h_z can be given as a recurrent relation:

$$h_z(t_{k+1}) = h_z(t_k) + v_z(t_k)\Delta t + \vartheta\cdot\Delta t^2\big/\left(m_1+m_2\right), \tag{10}$$

where $v_z(t_{k+1}) = v_z(t_k) + \vartheta\cdot\Delta t\big/\left(m_1+m_2\right)$ is the armature velocity; $\vartheta = i_1(t_k)i_2(t_k)\dfrac{dM_{12}}{dz}(z) - g(m_1+m_2)$,

m_1, m_2 is the weight of the armature and the TB, respectively.

The inductance of the n-th active element can be determined through the vector potential of the magnetic field when it is divided into elementary calculated circuits [13]. The mutual inductance between the n-th and m-th elementary circuits is determined by the method of Taylor series expansion [14].

Electromechanical processes in IDC during excitation by a single pulse

Let's consider the IDC with the following parameters: outer diameter of active elements $D_{ex} = 100$ mm, their inner diameter $D_{in} = 10$ mm. The IW height $H_1 = 10$ mm, height of the copper CA $H_2 = 2$ mm, number of the IW turns $N_1 = 46$ of wound copper bus with a cross section $a \times b = 1.8 \times 4.8$ mm^2. The TB mass $m_2 = 80$ g. The IDC is excited from the CES by a single pulse or packet of pulses at which the pushing of the armature together with the TB on the maximum height $h_{zm} = 120...160$ mm is provided. The total mass pushed is 220 g.

When the IDC is excited by a single pulse, let's consider the variant No. 1 of the CES low capacitance and overvoltage ($C_0 = 100$ µF, $U_0 = 730$ V) and the variant No. 2 of the CES large capacitance and under-voltage ($C_0 = 675$ µF, $U_0 = 210$ V) (Fig. 1).

When using the CES with low capacity C_0 and high voltage U_0 (variant No. 1), the amplitude of the current density in the IW is $j_{1m} = 155.7$ A/mm^2 in 0.075 ms, and the amplitude of the current density in the CA is $j_{2m} = 501.9$ A/mm^2. There is the EDF between the IW and the CA, the amplitude of which is $f_{zm} = 5092.8$ N. This provides acceleration of the armature with the TB to a velocity $v_z = 1.77$ m/s in 0.2 ms and the height of their push $h_{zm} = 158$ mm.

When using the CES with large capacity C_0 and low voltage U_0 (variant No. 2), all electromechanical processes are more stretched in time and smaller in amplitude. The amplitude of the current density in the IW reaches the value $j_{1m} = 100.9$ A/mm^2 in 0.18 ms, and the amplitude of the current density in the armature $j_{2m} = 306.0$ A/mm^2. When using such excitation, the EDF acts between the IW and the armature, the amplitude of which reaches $f_{zm} = 1993$ N. This provides acceleration of the armature with the TB to a velocity $v_z = 1.13$ m/s in 0.2 ms and the maximum height of their push $h_{zm} = 156$ mm. When using the CES of both variants, after some time (after ~ 0.35 ms) the velocities of the armature become almost the same, amounting to $v_z = 1.70...1.78$ m/s.

As the duration of the force interaction between the IW and the armature increases (variant No. 2), the amplitude of the EDF decreases, although it remains at a high level. We would like to admit that even in this variant, the duration of the force remains unacceptably short (0.4 ms).

Electromechanical processes in IDC during excitation of the IW by a pulse packet

Let's consider the effect of the duration, shape and amplitude of a packet of 10 short power pulses between the IW and the CA on the electromechanical processes in the IDC. The specified pulse packet is formed by connecting the CES sections to the IW with a time delay that determines the pulse period.

Fig. 2 shows the electromechanical characteristics of the IDC when excited by a pulse packet lasting 12 ms from the CES sections with the same parameters: $C_0 = 100$ µF, $U_0 = 320$ V. With this method of the IDC excitation, the current density amplitude in the IW j_{1m} is successively reduced from 68.8 A/mm^2 in the first pulse to 47.7 A/mm^2 in the tenth pulse.

A greater decrease in the amplitudes of the induced current density occurs in the armature j_{2m}: in the first pulse of the packet it is 222.1 A/mm^2, and in the tenth pulse – 84.9 A/mm^2. There is a consistent decrease in the amplitude of the EDF pulses f_{zm}: from 997.3 N in the first pulse to 101.5 N in the tenth pulse. During the action of the pulse packet (12 ms) the armature together with the TB receive a velocity $v_z = 1.59$ m/s and travel a distance $h_z = 13.7$ mm. This packet of pulses provides pushing the armature together with the TB to a height $h_{zm} = 140.7$ mm.

To reduce the amplitude of the EDF of the first pulse of the packet, let's consider the excitation of the IDC from the CES sections with different parameters C_0 and U_0. Fig. 3 shows the electromechanical characteristics

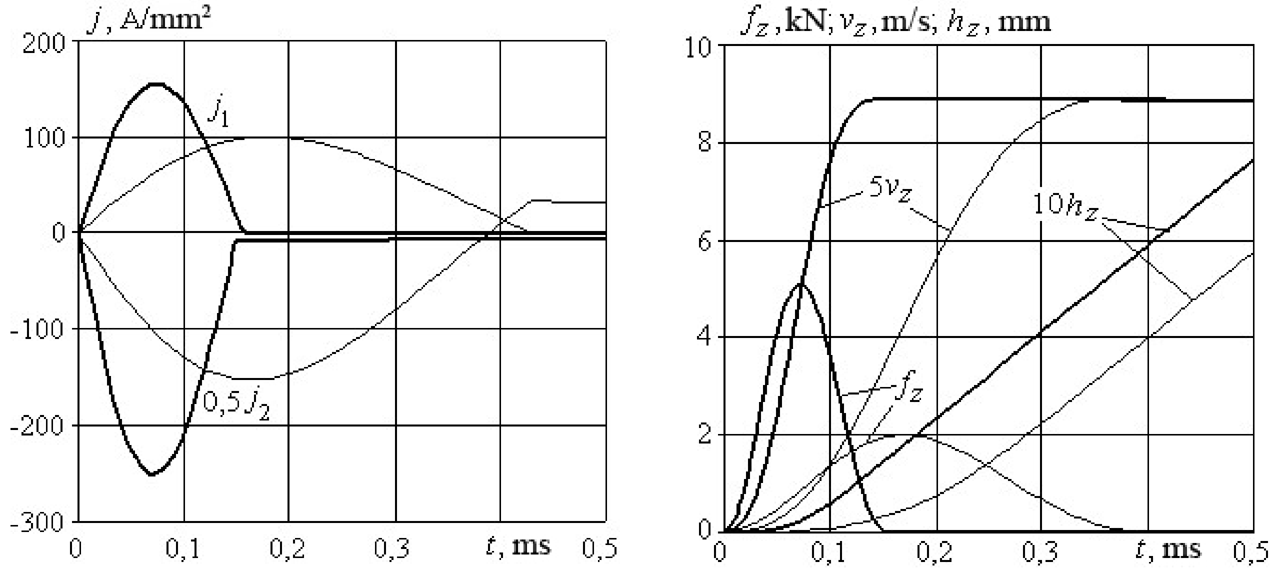


Fig. 1. Electromechanical characteristics of the IDC when excited by a single pulse: variant No. 1 of the CES (bold lines) and variant No. 2 of the CES (thin lines)

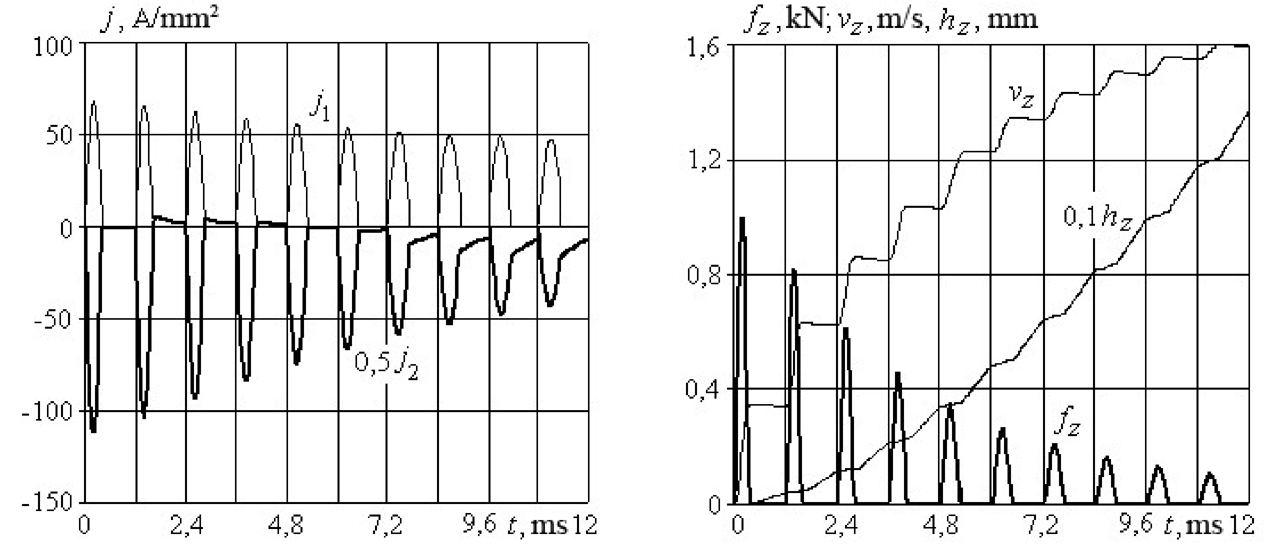


Fig. 2. Electromechanical characteristics of the IDC when excited by a packet of pulses from the CES sections with the same parameters: C_0 = 100 μF, U_0 = 320 V

of the IDC when excited by a packet of pulses from the CES sections of the same capacitance C_0 = 100 μF, but charged to a voltage U_0, which increases linearly from 150 to 420 V. With this excitation, the amplitude of the current density in the IW j_{1m} in all subsequent pulses of the packet gradually increases from 32.3 A/mm² in the first pulse to 67.3 A/mm² in the tenth pulse of the packet. The change in the amplitudes of the induced current density in the armature j_{2m} has the following pattern: in the first pulse, the amplitude is the smallest, 104.3 A/mm². In the following pulses, the amplitudes j_{2m} increase, reaching the highest value of 163.1 A/mm² in the seventh pulse, after which the amplitudes decrease to 150.8 A/mm² in the tenth pulse. In the first pulse, the amplitude of the EDF f_{zm} is the smallest, 218.5 N, then it increases, taking the largest value of 439.5 N in the fifth pulse, and then decreases. During the pulse packet, the armature together with the TB acquire a velocity v_z = 1.48 m/s and travel a distance h_z = 8.5 mm. This packet of pulses provides pushing the armature to a height h_{zm} = 132 mm.

Fig. 4 shows the electromechanical characteristics of the IDC when excited by a packet of pulses from the CES sections, charged to a voltage U_0 = 210 V, which capacity C_0 increases linearly from 50 to 500 μF. The period between pulses is 3 ms. With this excitation, the amplitude of the current density in the IW j_{1m} in all subsequent pulses of the packet also gradually increases from 32.8 A/mm² in the first pulse to 64.5 A/mm² in the tenth pulse. The values of the amplitudes of the induced current density in the armature j_{2m} have the following pattern: in the first pulse the amplitude is the smallest, 107.2 A/mm², in subsequent pulses the amplitudes j_{2m} increase, reaching the highest value of 157.5 A/mm² in the fourth pulse, then decrease to 76 A/mm² in the tenth pulse.

At this, the amplitude of the EDF f_{zm} in the first pulse of the packet is 228.2 N, then it increases, taking the largest value of 465.6 N in the third pulse of the packet, and then decreases, taking the smallest value of 81.3 N in the tenth pulse. During the pulse packet (30 ms), the armature together with the TB acquire a velocity v_z = 1.42 m/s and moves a considerable distance

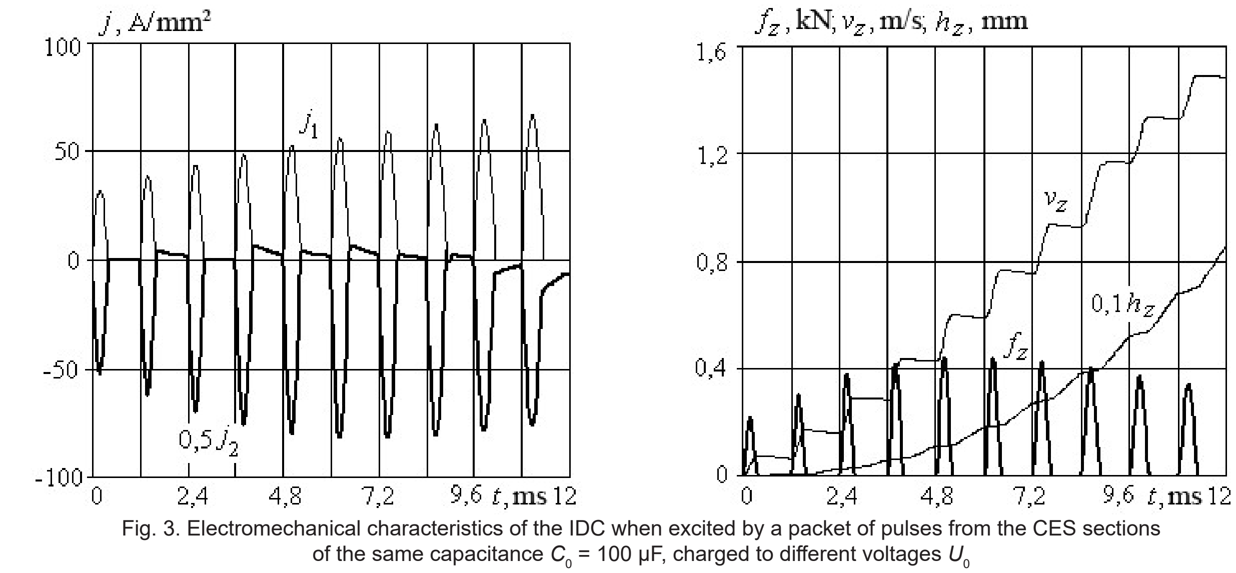


Fig. 3. Electromechanical characteristics of the IDC when excited by a packet of pulses from the CES sections of the same capacitance C_0 = 100 μF, charged to different voltages U_0

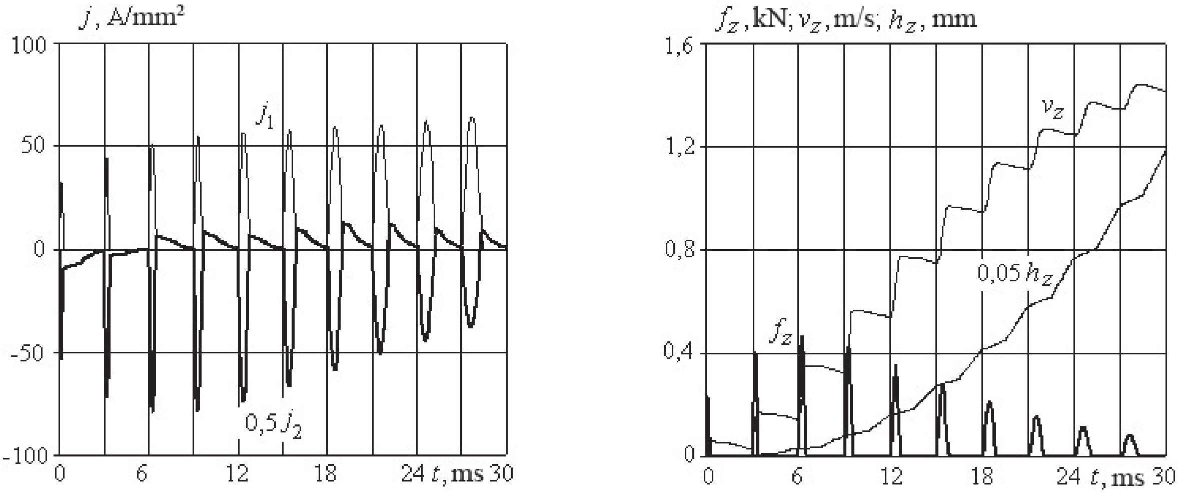


Fig. 4. Electromechanical characteristics of the IDC when excited by a packet of pulses with a period of 3 ms, from the CES sections charged to a voltage U_0 = 210 V, which capacity C_0 increases linearly

h_z = 23.7 mm. This packet of pulses provides pushing the armature to a height h_{zm} = 126.2 mm.

Thus, the excitation of the BLG catapult by a packet of sequential pulses provides the reduced auto seismic oscillations of the foundation by reducing the amplitudes of the EDF pulses and increasing the time of their effect. It is most appropriate to excite the IDC by the pulse packet from the CES sections of the same capacitance, but charged to a sequentially increased voltage, or from sections that have a sequentially increased capacitance, but charged to a single voltage.

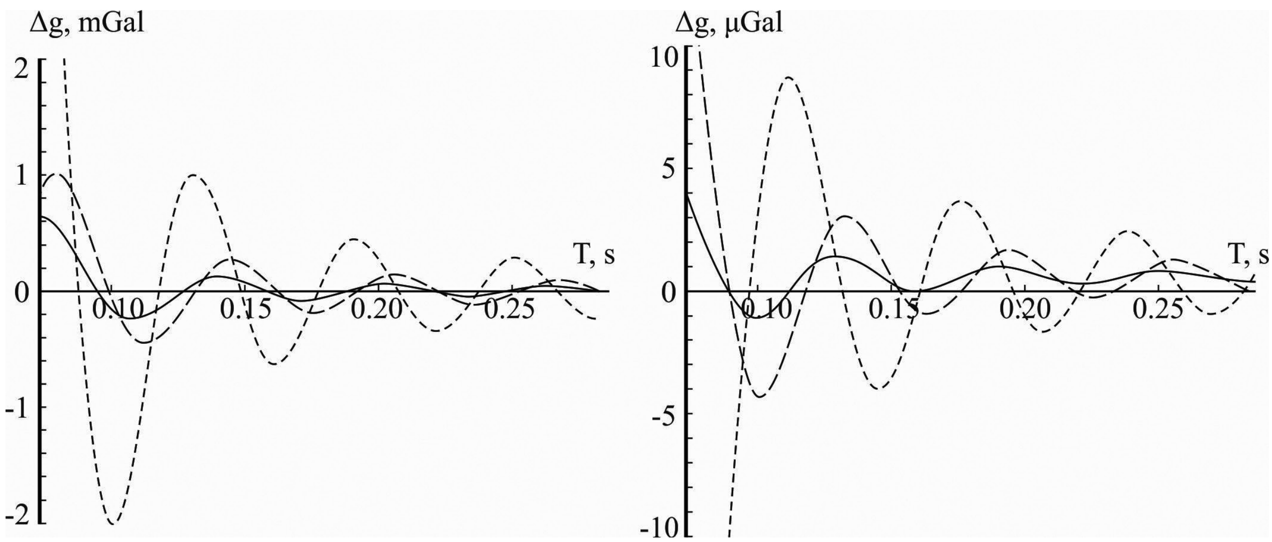
Investigation of the efficiency of the multi-impulse method of excitation of the BLG induction-dynamic catapult

Let's consider the effect of excitation of the BLG induction-dynamic catapult by a pulse packet on the auto seismic uncertainty component (ASU) of the measurement of g in comparison with the excitation of the catapult by a single pulse. The value of the auto seismic uncertainty component of the measurement of g is estimated by modeling the mechanical system of the BLG [7, 15, 16]. When modeling, we use the following parameters of the mechanical system of the BLG [15–17]: the foundation mass m_0 = 3000 kg, the stiffness of the soil base c_0 = 125.88 MN/m, the coefficient of viscous friction of the base b_0 = 73743.2 N · s/m; the TB mass m = 0.08 kg; the TB initial velocity v = 1.4 m/s (which corresponds to the push of the TB to a height of about 0.10 m).

An elastic suspension of the BLG interferometer reference reflector is used as a vibration protection system [17]. At this, the mass of the reference reflector is taken to be equal m_v = 0.1 kg, and the period of the proper oscillations of the vibration protection system is 10 s. We assume that the vibration protection system works in a critical mode. As an indicator of efficiency, we take the ASU of the GA measurement, which is determined by the expression [17]

$$\Delta g = -\sum_{k=0}^{K-1} x_v(kh + t_0 - \frac{T}{2}) \cdot w(k), \quad (11)$$

where $x_v(t)$ is the process of moving the reference reflector; h is the sampling interval of count processing of the path travelled by the TB; t_0 is the point of time when the TB reaches the top; $w(k)$ are the weighting



a *b*

Fig. 5. Auto seismic uncertainty component of g measurement for the BLG without (*a*) and with (*b*) vibration protection

factors of path-time count processing in the BLG; T is the duration of the processing interval.

The sampling interval h in equation (11) we choose equal to 0.5 ms. At this, the processing factors $w(k)$ corresponding to the method of least squares are used.

The modeling results presented in the form of graphs in Fig. 5 (*a*), (*b*) show the dependences of the auto seismic uncertainty component of g measurement on the duration of the processing interval T. In this Fig., the curves correspond to different excitation signals of the BLG electrodynamic catapult: 1) a curve with a short dotted line – a single excitation pulse lasting 1 ms; 2) a curve with a long dotted line – a packet of ten pulses lasting 1 ms with a period between pulses 2 ms; 3) solid curve – a packet of ten pulses lasting 1 ms with a period between pulses 5 ms. The intensities of the excitation pulses in all three cases are chosen so as to provide the same initial velocity of the TB v = 1.4 m/s.

From the analysis of the obtained dependences of the ASU value of g measurement it is concluded that the transition from the method of excitation of the BLG induction-dynamic catapult with one short pulse to its excitation by the packet of pulses of the same duration allows to significantly reduce the uncertainty of g measurement by the gravimeter with the symmetric measurement method on account of reducing the auto seismic component of uncertainty in 3–5 times.

Conclusions

The mathematical model of the IDC describing interconnected electric, magnetic and mechanical processes is developed. It is found that when the IDC is excited by a packet of ten pulses, the duration of which is equal to 12 ms, from the CES sections with the same parameters, a consistent reduction in the amplitudes of the EDF pulses is observed. When the IDC is excited by a packet of pulses from the CES sections of the same capacitance, but charged to a voltage U_0, which linearly increases, the amplitude of the EDF is the smallest in the first pulse, then it reaches a maximum value in the fifth pulse. When the IDC is excited by a packet of pulses from the CES sections charged to a voltage U_0 = 210 V, the capacitance C_0 of which increases linearly, the amplitude of the EDF reaches the highest value in the third pulse. Reducing the pulse period does not change the nature of the amplitudes of currents and the EDF in the catapult, but provides the pushing of the armature with the TB to a greater height.

The transition from the excitation method of the BLG induction-dynamic catapult with one short pulse to its excitation by a series of ten pulses of the same duration allows to significantly reduce the uncertainty of the GA measurement by the gravimeter with the symmetric measurement method by reducing the auto seismic component of the uncertainty of the GA measurement by 3–5 times.

Зменшення автосейсмічних коливань балістичного лазерного гравіметра за рахунок збудження індукційно-динамічної катапульти пакетом імпульсів

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Анотація

Для зменшення автосейсмічних коливань у балістичних лазерних гравіметрах з симетричним методом вимірювання прискорення вільного падіння використовується індукційно-динамічна катапульта (ІДК), яка збуджується пакетом імпульсів від ємнісного накопичувача енергії. При такому збудженні досягається зменшення амплітуди автосейсмічних коливань за рахунок зменшення амплітуди та збільшення тривалості дії електродинамічної сили, яка виникає в індукційно-динамічній катапульті при підкиданні пробного тіла (ПТ).

Розроблено математичну модель індукційно-динамічної катапульти балістичного лазерного гравіметра з симетричним методом вимірювання прискорення вільного падіння та проведено моделювання її електромеханічних характеристик. Розглянуто різні способи формування пакету імпульсів збудження індуктора ІДК і для них досліджено характеристики імпульсів електродинамічних зусиль, що здійснюють розгін якоря катапульти з ПТ. Досліджено вплив збудження індукційно-динамічної катапульти пакетом імпульсів на автосейсмічну складову вимірювання прискорення вільного падіння. Показано, що за рахунок збудження індукційно-динамічної катапульти пакетом із десяти імпульсів можна зменшити автосейсмічну складову невизначеності вимірювання прискорення вільного падіння балістичними гравіметрами в декілька (3–5) разів у порівнянні зі збудженням катапульти одиничним імпульсом.

Ключові слова: балістичний лазерний гравіметр; індукційно-динамічна катапульта; автосейсмічна складова невизначеності вимірювання.

Уменьшение автосейсмических колебаний баллистического лазерного гравиметра за счет возбуждения индукционно-динамической катапульты пакетом импульсов

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Аннотация

Для уменьшения автосейсмических колебаний в баллистическом лазерном гравиметре с симметричным методом измерения ускорения свободного падения (УСП) используется индукционно-динамическая катапульта (ИДК), которая возбуждается пакетом импульсов от емкостного накопителя энергии. При таком возбуждении достигается уменьшение амплитуды автосейсмических колебаний за счет уменьшения амплитуды и увеличения длительности действия электродинамической силы, которая возникает в ИДК при подбрасывании пробного тела.

Разработана математическая модель индукционно-динамической катапульты гравиметра с симметричным методом измерения УСП и выполнено моделирование ее электромеханических характеристик. Исследовано влияние возбуждения ИДК пакетом импульсов на автосейсмическую составляющую неопределенности измерения ускорения свободного падения. Показано, что за счет возбуждения ИДК пакетом из десяти импульсов можно уменьшить автосейсмическую составляющую неопределенности измерения УСП баллистическими гравиметрами в 3–5 раз в сравнении с возбуждением катапульты единичным импульсом.

Ключевые слова: баллистический лазерный гравиметр; индукционно-динамическая катапульта; автосейсмическая составляющая неопределенности измерения.

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