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OPTIMIZATION OF THE DYNAMIC PARAMETERS OF AN OBJECT IN A MATHEMATICAL MODEL OF SEISMO-ACOUSTIC MONITORING OF NATURAL AND ENGINEERING OBJECTS

Introduction

Structural analysis and identification of the dynamic parameters of structures and signal sources whose spectral characteristics lie in the seismic and lower acoustic ranges are extremely important in their monitoring to predict significant changes in dynamic characteristics. By their nature, these are man-made and natural objects. The dynamic identification method provides the ability to investigate the dynamic behavior of a given structure through non-destructive testing and therefore allows an assessment of the state of the structure and the possible need for more detailed monitoring. A methodology is proposed for identifying the main structural parameters, such as the main natural frequencies and the quality factor of the structure at these frequencies. The method of examining the response of a structure to a dynamic load is analyzed, which can be any: environmental (wind, sea waves, traffic, and so on) or artificially caused by testing impulses. For the creation model of a seismic signal, we took into account the fundamental empirical research of seismic signals, and mathematical models were used for their approximation [1,2]. Also, we used the streaming nature of the seismic process and considered that the seismic signal must be a wave, as was noticed in [3].

Analysis of recent research and publications

Of particular interest is the passive monitoring of objects with sources of emission signals, the parameters of which are to be determined and are characteristic of the structure. The issue can be both irregular and regular. In the latter case, it can be modeled as a flow with probabilistic characteristics to be determined [4–6]. This behavior is typical for geological faults as a source of seismic signal emission. Such a flow, if it is modeled as binomial, may have, in contrast to the model in active monitoring, a greater probability of the source "not triggering" i.e., the integral of the partial probability density of the signal occurrence at a given quantity of moments on a set of moments, appearing on the given interval, It can be much less than unity. While active monitoring can be organized so that the value of this integral will be close to unity. The dispersion of the distribution of the moments of the start of the emission of individual signals is significantly larger than in the case of active monitoring.

The significant differences between the two types of monitoring do not end there. In active monitoring, the researcher also has at his disposal a probing signal. This means that the result of the analysis of data obtained in passive monitoring of this type of signal is reduced to estimating the parameters of the emission signal, which fluctuate from signal to signal, and the distribution of parameter fluctuations is a priori unknown. A particularly important emission modeling case is "short" i.e., well-resolved signals. Note that the physical realizability of the signal is to satisfy two conditions. These conditions have causality and stability [7]

Problem Statement

Mathematical model of physically realizable seismic signals

A superposition of oscillators well approximates a physically realizable signal, but for real physical systems with a narrow spectral band and, accordingly, as a consequence, wavefront damping, it is natural to model by a superposition of Berlage pulses [1] as a generalization of an oscillator.

$$y(t) = \eta(t)te^{-\alpha t}\sin(\omega t). \qquad (1)$$

For model (1), the following generalization is natural. For the Berlage momentum, which entered at the moment of time τ

$$y(t) = A\eta(t-\tau)(t-\tau)\exp\{-\alpha(t-\tau)\}\times \sin\left[\omega(t-\tau)\right]. \qquad (2)$$

In (2) $\eta(t-\tau)$ – is the Heaviside function.

The following natural generalization of the model (generalized Berlage function):

$$y(t) = A\eta(t-\tau)(t-\tau)^{\beta}\times \exp\{-\alpha(t-\tau)\}\sin\left[\omega(t-\tau)\right] \qquad (3)$$

In formulas (1–3) $y(t)$ – observed data, $\{A,\tau,\alpha,\omega,\beta\}$ – vector of free parameters of the model, where A – oscillation amplitude, τ – signal arrival time, α – parameter characterizing signal attenuation (decrement), ω – signal frequency, β – is the parameter that characterizes the velocity of the beginning of the signal..

At $\beta=1$ we have the Berlage momentum; at $\beta=0$ we have an oscillator,at $\beta\neq 0 \vee \beta \neq 1$ we have the generalized Berlage momentum; at $\alpha=\beta=0$ we have the first Fourier harmonic on the interval $\left(\tau,\tau+\dfrac{2\pi}{\omega}\right)$. In what follows, we consider the general case, fixing the free parameters α and β, proceed to particular cases of the generalized Berlage momentum.

A model consisting of K submodels and representing a superposition of impulses, each of which is given by formula (1–b) and enters the model as a row vector of physically meaningful free parameters of the generalized Berlage impulse, each of the impulses is completely determined by a row vector:

$$\mathbf{P}_{\langle k\rangle} = \{A_k,\tau_k,\alpha_k,\omega_k,\beta_k\}. \qquad (4)$$

And the model takes the form:

$$M(t,\mathbf{P}) = \sum_{k=1}^{K} A_k\eta(t-\tau_k)(t-\tau_k)^{\beta_k} \exp\{-\alpha_k(t-\tau_k)\}\sin\left[\omega_k(t-\tau_k)\right]+n(t). \qquad (5)$$

In (5), the model's free parameters matrix $\mathbf{P}$ is given. The row vector $\mathbf{P}_{\langle k\rangle}$ of this matrix completely determines of the k-th submodel, and the column vector $\mathbf{P}^{\langle s\rangle}$ which determines the related parameters of the submodels, $n(t)$ is the additive noise. In (1.6) there are five related parameters:

$$\mathbf{P} = \{P_{k,s}\},\ k=\overline{1,K},\ s=\overline{1,S}. \qquad (4\text{-a})$$

S – is the number of free parameters in the submodel (the number of columns in the matrix is $\mathbf{P}$), K – is the number of submodels (the number of rows in the matrix is $\mathbf{P}$). Thus a rectangular matrix of free parameters of model with dimensions $K\times S$ in (4) defines the model (5).

If we combine related vectors into the matrix, then:

$$\mathbf{P} = \left\{\mathbf{P}^{\langle 1\rangle},\mathbf{P}^{\langle 2\rangle},\mathbf{P}^{\langle 3\rangle},\mathbf{P}^{\langle 4\rangle},\mathbf{P}^{\langle 5\rangle}\right\}, \qquad (6)$$

In (6) are given vectors of the form:

$$\mathbf{P}^{\langle 1\rangle} = \mathbf{A} = \begin{Bmatrix} A_1\\ \vdots\\ A_k\\ \vdots\\ A_K\end{Bmatrix};\ \mathbf{P}^{\langle 2\rangle} = \boldsymbol{\tau} = \begin{Bmatrix} \tau_1\\ \vdots\\ \tau_k\\ \vdots\\ \tau_K\end{Bmatrix};$$

$$\mathbf{P}^{\langle 3\rangle} = \boldsymbol{\alpha} = \begin{Bmatrix} \alpha_1\\ \vdots\\ \alpha_k\\ \vdots\\ \alpha_K\end{Bmatrix};\ \mathbf{P}^{\langle 4\rangle} = \boldsymbol{\omega} = \begin{Bmatrix} \omega_1\\ \vdots\\ \omega_k\\ \vdots\\ \omega_K\end{Bmatrix}; \qquad (6\text{-a})$$

$$\mathbf{P}^{\langle 5\rangle} = \boldsymbol{\beta} = \begin{Bmatrix} \beta_1\\ \vdots\\ \beta_k\\ \vdots\\ \beta_K\end{Bmatrix}$$

Thus, the model in terms of the matrix of free parameters takes the form:

$$M(t,\mathbf{P}) = \sum_{k=1}^{K}\mathbf{P}_k^{\langle 1\rangle}\eta(t-\mathbf{P}_k^{\langle 2\rangle})(t-\mathbf{P}_k^{\langle 2\rangle})^{\mathbf{P}_k^{\langle 5\rangle}}\times \exp\left\{-\mathbf{P}_k^{\langle 3\rangle}(t-\mathbf{P}_k^{\langle 2\rangle})\right\}\sin\left[\mathbf{P}_k^{\langle 4\rangle}(t-\mathbf{P}_k^{\langle 2\rangle})\right]. \qquad (5\text{-a})$$

Here vectors are $\mathbf{A},\boldsymbol{\tau},\boldsymbol{\alpha},\boldsymbol{\omega},\boldsymbol{\beta}$ column vectors consisting of K rows K – is the number of submodels. The matrix $\mathbf{P}$ is formed as a union of vectors $P_{k,s} = P_k^{\langle s\rangle}$ (6). In the given model $s=\overline{1,S}; S=5..2)$ For model (6) and field observations $V(t)$ on the interval $(0,T)$, we construct the objective function $Q(\mathbf{P})$ in the metric

$L_2(0,T)$. $T = \Delta t \cdot S1$, here Δt is the time quantum, $S1$ is the number of sampling points in the interva l.

$$Q(\mathbf{P}) = \| V_{s1} - M(t_{s1}, \mathbf{P}) \|_{L_2}, \quad k = \overline{1,K}; \tag{7}$$

$$Q(\mathbf{P}) = \sqrt{\frac{1}{T}\sum_{s1=0}^{S1}(V_{s1} - M(t_{s1}, \mathbf{P}))^2}, \tag{7-a}$$
$$t_{s1} = s1 \cdot \Delta t; T = t_S \cdot \Delta t.$$

To find the extrema of the function $Q(\mathbf{P})$, you need to solve the system of equations for all elements of the matrix $\mathbf{P}$:

$$\frac{\partial Q(\mathbf{P})}{\partial P_{s,k}} = 0, \; k = \overline{1,K}; s = \overline{1,S}. \tag{8}$$

Given the similarity of related submodels, we can sequentially consider derivatives in the vectors' $\mathbf{P}^{\langle k \rangle}$ direction and related parameters of different submodels.

$$\frac{\partial Q(\mathbf{P})}{\partial \mathbf{P}^{\langle k \rangle}} = \begin{Bmatrix} \dfrac{\partial Q(\mathbf{P})}{\partial \mathbf{P}_1^{\langle k \rangle}} \\ \cdots \\ \dfrac{\partial Q(\mathbf{P})}{\partial \mathbf{P}_S^{\langle k \rangle}} \end{Bmatrix} = \mathbf{0} = \begin{Bmatrix} 0 \\ \cdots \\ 0 \end{Bmatrix}. \; k = \overline{1,K} \tag{8-a}$$

Of the set of extrema, it is necessary to single out the global minimum.

But working with such kind of model for the flow of signals are associated with the difficulties of using the variation approach [8] to the problem of estimating the parameters of the flow. Taking into consideration that the process is accompanied by microseismic background [9], we cannot accurately estimate the parameters of the signal in the stream.

Optimal estimation of the vector of free parameters of the model

So we find the global minimum of the functional $Q(\mathbf{P}_k)$ on the set of admissible, with a priori, known distribution, vectors $\mathbf{P}_k$ from the set $\mathfrak{A}_k$ [10].

$$\min_{\mathbf{P}_k} \{ Q(\mathbf{P}_k) \}; \; k = \overline{1,K}; \; \mathbf{P}_k \in \mathfrak{A}_k$$

The results of calculations for the model of three damped harmonics are reduced to vectors of dimension 4, with a fixed vector of arrival time parameters, combining one-dimensional parameters, i.e., a 12-parametric model is considered.

Fig. 1 shows the dependence of the goodness of fit criterion of the model on such nonlinear parameters entering the model as the oscillation frequency of the object. Here, the dependence of the criterion (7-a) on two of the twelve free parameters of the selected model, namely the frequencies of the first and second harmonics, is given, with the remaining parameters of the 12-dimensional vector fixed. These parameters enter the model non-linearly. As a result, we see a complex, gully-like surface topography with many local extrema. This type of criterion determined the approach to the search for the global minimum adopted in this work, namely the method of random search by a priori distributions [11].

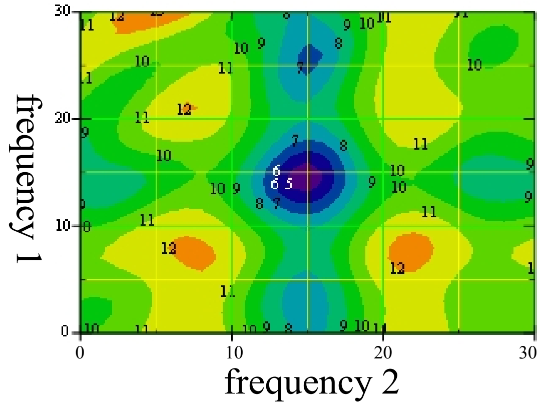

Fig. 1. Dependence of the criterion of fit of the model on the parameters nonlinearly included in the model: the frequencies of the first (along the abscissa) and second (along the ordinate) harmonics of the object oscillations with other fixed parameters

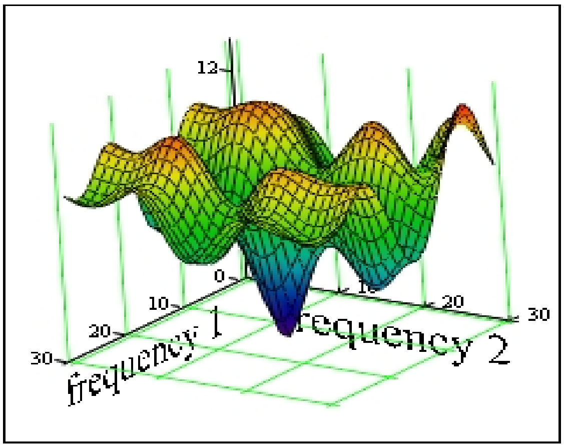

Fig. 2. Topography of the criterion presented in Fig. 1

The topography of the criterion is given in Fig. 2, where it is easy to trace local extrema in the range of possible values of these parameters accepted for calculation. In the Fig., along the abscissa axis, the first, and along the ordinate axis, the second harmonic of the object's oscillations are plotted.

These Fig. show how close in the parameter space you need to get to the global minimum point in the Monte Carlo method to avoid reaching a local minimum and getting a non-optimal solution.

The situation is much simpler for the parameters linearly included in the model since for these parameters, the functional (7-a) (for fixed nonlinear parameters) is concave, and the extremum point is unique. This can be seen by analyzing Fig. 3 and 4. As two independent variables of the criterion (7-a), the values of the amplitudes of the first and second harmonics are selected, while the remaining parameters are fixed (Fig. 3, 4).

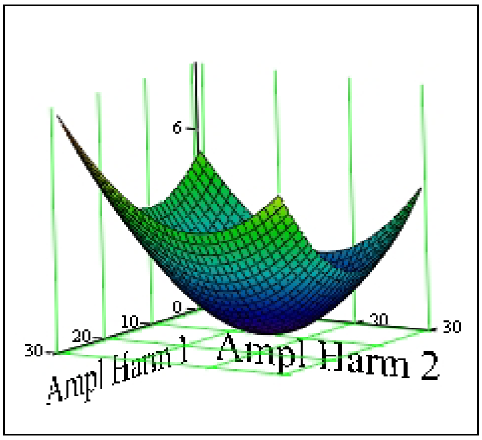

Fig. 3. Dependence of the criterion of fit of the model on the parameters linearly included in the model: the amplitudes of the first (along the abscissa) and second (along the ordinate) harmonics of the plant oscillations (with other fixed parameters)

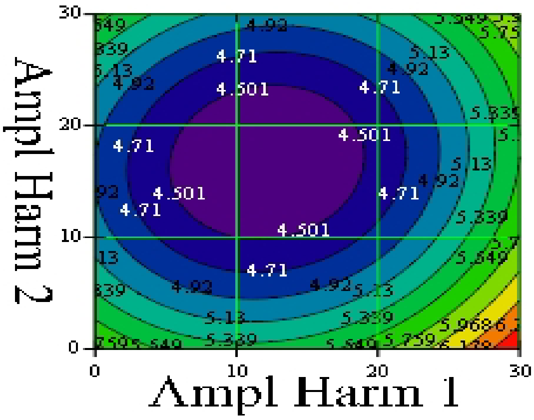

Fig. 4. Topography of the criterion presented in Fig. 3

If, for example, the amplitudes of the first and second harmonics are chosen as two independent variables of criterion (7-a), and while the remaining parameters are fixed, then in this case, in three-dimensional space, the criterion looks like it is shown in Fig. 3.

The nature of the nonlinearity of the parameters included in the model makes it possible to make predictions about the behavior of the criterion when one or another of them changes.

Since the parameters that determine the phase of the corresponding harmonics, which are included in the model nonlinearly, have a period, prior distributions in the Monte Carlo method are considered on the interval $[-\pi,\pi]$. This can be traced by analyzing Fig. 5 and 6, where the criterion is presented as a function of the phase shift and the circular frequency of the first harmonic with other parameters fixed. Here, as before, Fig. 5 is the criterion, in Fig. 6 is the topography of the criterion (7-a) of the free parameters of the phase and frequency of the first harmonic, with the remaining fixed parameters of the criterion.

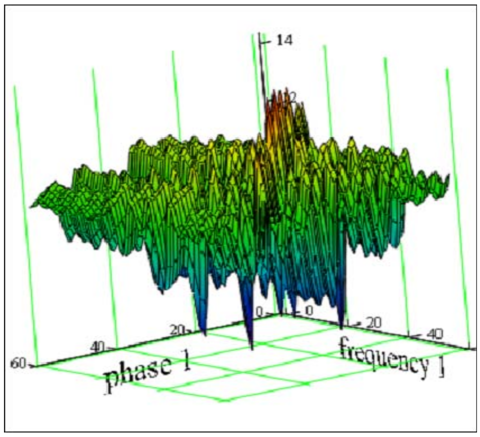

Fig. 5. Criterion as a function of phase shift and circular frequency of the first harmonic with other fixed parameters

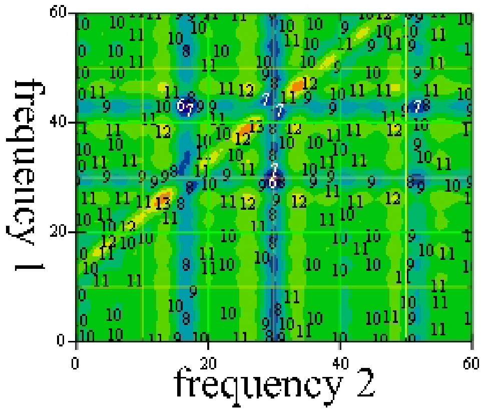

Fig. 6. Topography of the criterion presented in Fig. 5, where the abscissa is the frequency, and the ordinate is the phase shift

If the values of the exponent of the damped exponent of the third harmonic and its frequency are chosen as two independent variables of the criterion (7-a) while the remaining parameters are fixed, then in this case, in three-dimensional space, the criterion looks like it is shown in Fig. 7 and 8.

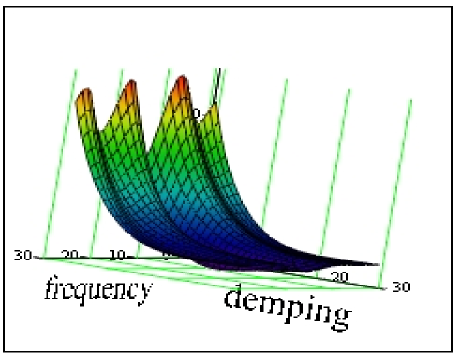

Fig. 7. Criterion as a function of the exponent of the decaying exponent of the third harmonic and its frequency with other fixed parameters

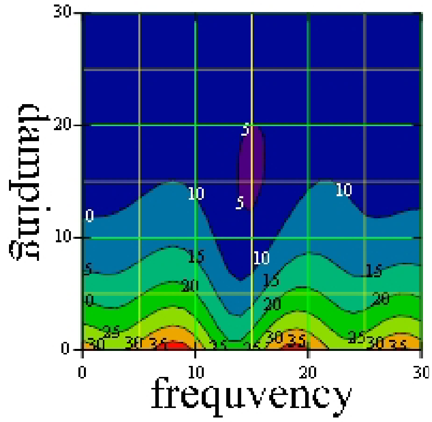

Fig. 8. Topography of the criterion shown in Fig. 7, where the abscissa is the frequency, and the ordinate is the exponent

The topography of the criterion is shown in Fig. 9, where the abscissa is the frequency, and the ordinate is the exponent. Sections of this criterion by planes, one of which is perpendicular to the abscissa axis and passing through the global minimum point (Fig. 9), and the other – to the ordinate axis (Fig. 10).

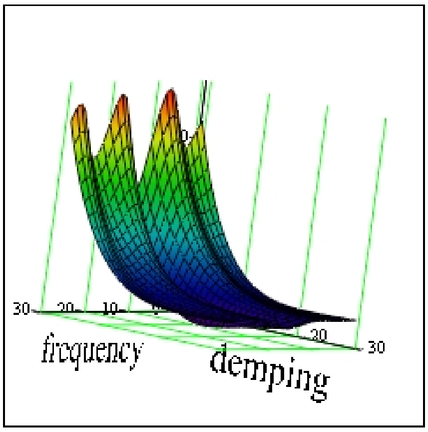

Fig. 9. Criterion as a function of the exponent of the first harmonic and its frequency with other fixed parameters

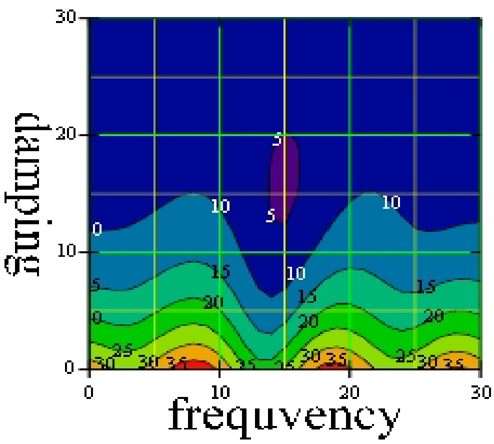

Fig. 10. Topography of the criterion presented in Fig. 9, the dependence of criterion (7-a) on the parameters of the exponent of the first harmonic and its frequency with other fixed parameters

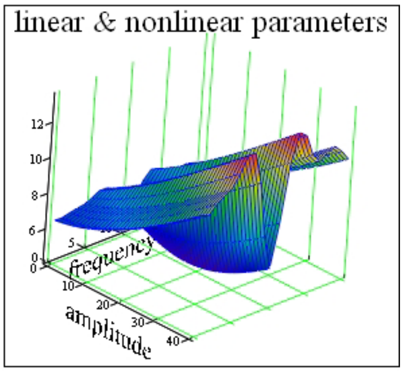

Fig. 11. Criterion as a function of the frequency of the first harmonic and the amplitude parameter of the first harmonic with other fixed parameters

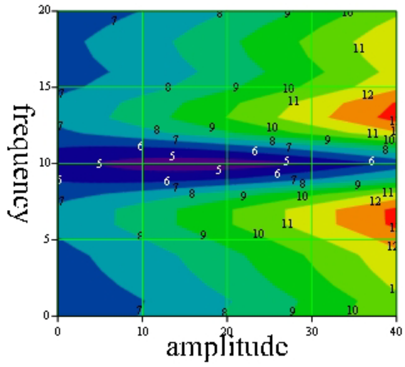

Fig. 12. Topography of the criterion presented in Fig. 11, criterion (7-a) as a function of the first harmonic frequency and amplitude parameter of the first harmonic

Processing of field observations

Let us consider an optimized procedure for estimating the dynamic parameters of mortar explosion signals with characteristics in the seismo-acoustic frequency range using the example of the data obtained from the monitoring study and allowed signals of mortar explosions.

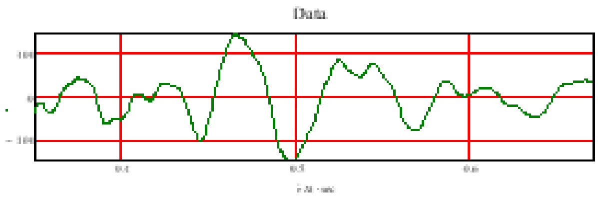

Fig. 13. Fragment of a mortar explosion signal recording against background noise

The abscissa shows the time in milliseconds; the ordinate indicates the amplitude of the oscillation velocity in relative units.

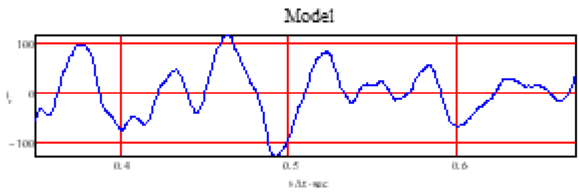

Fig. 14. Model approximating the signal shown in Fig. 13, the free parameters of which are obtained as a result of estimating the optimal parameters of the criterion (7-a)

The abscissa shows the time in seconds; the ordinate indicates the amplitude of the oscillation velocity in relative units.

Let us proceed to the analysis of the quality of the optimal model. Consider a model with twelve free parameters. The criterion's value assesses the model's quality at the global minimum point. Fig. 15 represents, from the authors' point of view, the most important characteristics of the object, namely the quality factor of the system at natural frequencies. Fig. 15 shows the decay exponents of the energy dissipation process at natural frequencies for the 12-parametric model (three natural frequencies are considered here).

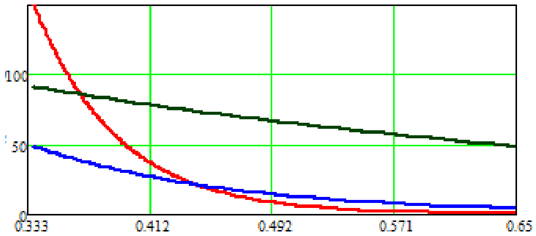

Fig. 15. Damping the energy dissipation process exponents at natural frequencies for the 12-parametric model

Fig. 16 shows each of the three submodels of the 12th parametric model (5). The intersection of each of the harmonics of the y-axis gives an idea of the estimate of its phase shift. We can see a significant difference in the object's state in the energy sense at different harmonics.

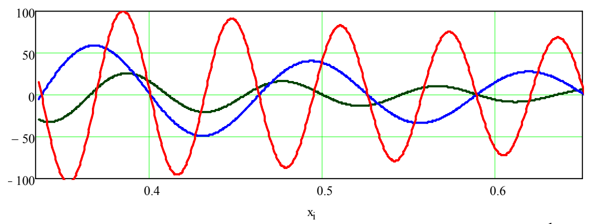

Fig. 16. Each of the three submodels of the 12th parametric model (17). The abscissa shows time in seconds; the ordinate indicates the values of the exponents that modulate the corresponding harmonics (in relative units)

Fig. 17 is the green curve model and the observed data (blue curve).

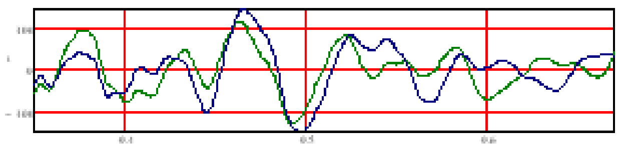

Fig. 17. Model (5) (green curve) and data obtained from the experiment (signal, blue curve)

The above calculations show the entire chain in the computerized technology for estimating free parameters in models and are provided only for one of the components of the oscillation velocity record.

First, the frequencies' values and logarithmic decrement of the object of study have a physically meaningful value. The latter is significant since they give an idea of the quality factor of the system, its ability to accumulate and retain for a while the energy of external disturbances. A high-quality factor (small decrement) at some frequencies in the model characterizes the particular sensitivity of the object to external disturbances at these frequencies. For example, dynamic changes in the decrement in the direction of decrease are a sign of the object's readiness for destruction from a weak external influence. Unfortunately, the Monte Carlo method used in the article gives convergence to the solution only in probability. Therefore, the number of calculation cycles should be large enough to ensure the correctness of the result, which becomes difficult with a large model dimension. Or it would be best if you had good a priori ideas about the expected result. In conclusion, we'd like to present the best parameters for the studied object.

Transposed vector of natural angular frequencies

$$\boldsymbol{\omega}^T = \{3.024 \quad 8.734 \quad 19.985\} \frac{rad}{\text{sec}}.$$

Transposed model amplitude vector (5).

$$\mathbf{A}^T = \{9.850 \quad 0.598 \quad 0.319\}.$$

Transposed decrement vector at eigen frequencies

$$\boldsymbol{\alpha}^T = \{0.019 \quad 2.124 \quad 0.197\}$$

Transposed vector of phase shifts in radians

$$\boldsymbol{\psi}^T = \{3.138 \quad 3.035 \quad 7.851\text{E-}3\}\, rad$$

Conclusions

A practical method for analyzing natural and man-made objects, whose natural frequencies lie in the seismic and lower part of the acoustic frequency ranges, based on monitoring their dynamics, is proposed. A new approach is proposed for identifying the state of such objects. A non-traditional model of the natural background of the monitored object is proposed in the form of a superposition of Berlage impulses. Such a model makes it possible to estimate such an essential parameter in the description of an object as its quality factor, the dynamics of which can give an idea of its structural changes. To predict the behavior of natural and engineering objects to prevent undesirable consequences of the behavior of the object under study, seismo-acoustic monitoring systems are used. The mathematical model and algorithm proposed by the authors can be integrated into the system of seismo-acoustic monitoring of natural and man-made objects.

REFERENS

[1] Michael J. Bianco, Peter Gerstoft, James Traer, Emma Ozanich. Tachine learning in acoustics: Theory and applications. *The Journal of the Acoustical Society of America*. Vol. 5(146). p.p. 3590–3628 (2019).

[2] Lengyel Károly, Ovidiu Stan,*Liviu Miclea. Seismic Model Parameter Optimization for Building Structures. 2020 Apr. 20(7). p. 567–592.

[3] Addison Paul S. The illustrated wavelet transform handbook. IOP Publishing Ltd 2002. 353 p.

[4] Mostovoy S., Mostovoi V. Active Monitoring and decision making problem. *IJ ITA*. Vol. 12, Number 4, Sofia, 2005, p. 127–135.

[5] Mostovoy S.V., Mostovoy V.S. Osadchuk A.E. Model of active seismic monitoring. *Gefiz. Journal*. 2005. Vol. 24, No. 6. P. 132–138.

[6] Lebedich I. N., Mostovoy S. V., Mostovoy V. S. Modern approaches to the analysis of the dynamic stability of natural and man-made objects on the example of monitoring a column-type monument. *Gefiz. Journal*. 2004. Vol. 24, No. 6. P. 132–138.

[7] Robinson E. Predictive decomposition of time series with application to seismic exploration. *Ibid*. 2017. 32, No 3. P. 418–484.

[8] Kirkpatrick S., Gelatt C., Vecchi M. Optimization by simulated annealing. *Science*. 1983. 220. P. 671–680.

[9] Mostovoy V. S., Mostovyi S. V., Panchenko M. V. Seismic signal and microseismic background phone (mathematical models and estimations). *Geoinformatic*. 2008. No 1, p. 28–38.

[10] Plessix R.-E. A review of the adjoint-state method for computing the gradient of a functional with geophysical applications. *Geophys. J. Int*. 2006. 167, 495.

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ОПТИМІЗАЦІЯ ДИНАМІЧНИХ ПАРАМЕТРІВ ОБ'ЄКТА ТА МАТЕМАТИЧНА МОДЕЛЬ СЕЙСМО-АКУСТИЧНОГО МОНІТОРИНГУ ПРИРОДНИХ ТА ІНЖЕНЕРНИХ ОБ'ЄКТІВ

Стаття присвячена підходу математичного моделювання сейсмоакустичного моніторингу об'єктів і споруд розмірів, власні частоти та сигнали випромінювання яких є сейсмічними та нижньою частинами акустичного діапазонів. Структурний аналіз та визначення динамічних параметрів таких конструкцій надзвичайно важливі при їх моніторингу для прогнозування істотних змін динамічних характеристик. Крім того, метод динамічної ідентифікації дає можливість досліджувати динамічну поведінку даної структури або джерела походження сигналу шляхом дослідження досліджуваних об'єктів з метою вивчення інформативних характеристик. У статті наведено методологію ідентифікації основних структурних параметрів, таких як основні власні частоти, і декремент цих частот. Особливий інтерес представляє сейсмоакустичний моніторинг об'єктів з джерелами сигналів випромінювання, параметри яких підлягають визначенню та є характеристиками структури або походження сигналу. Викиди можуть носити як нерегулярний, так і регулярний характер. Останній випадок може бути змодельований як потік з правдоподібними характеристиками та визначеннями предмета. Результат аналізу даних, отриманих при сейсмоакустичному моніторингу таких сигналів, зводиться до оцінки параметрів сигналу випромінювання, який коливається від сигналу до сигналу. Таким чином запропоновано практичний метод аналізу природних та техногенних об'єктів, власні частоти яких лежать у сейсмічному та нижній частині діапазонів акустичних частот, заснований на моніторингу їх динаміки. Запропоновано новий підхід до визначення стану таких об'єктів. Запропоновано нетрадиційну модель природного фону об'єкта моніторингу у вигляді суперпозиції імпульсів Берлаге. Така модель дає змогу оцінити такий суттєвий параметр в описі об'єкта, як його добротність, динаміка якої може дати уявлення про його структурні зміни. Для прогнозування поведінки природних та інженерних об'єктів з метою запобігання небажаних наслідків поведінки досліджуваного об'єкта використовуються системи сейсмоакустичного моніторингу. Запропоновані авторами математична модель і алгоритм можуть бути інтегровані в систему сейсмоакустичного моніторингу природних і техногенних об'єктів.

Ключові слова: система моніторингу, сейсмічний сигнал, сейсмічна хвиля, сейсмоакустичний моніторинг, математична модель.

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OPTIMIZATION OF THE DYNAMIC PARAMETERS OF AN OBJECT IN A MATHEMATICAL MODEL OF SEISMO-ACOUSTIC MONITORING OF NATURAL AND ENGINEERING OBJECTS

The article is devoted to the mathematical modeling approach of seismo-acoustic monitoring of objects and structures of sizes whose own frequencies and emission signals are from seismic and the bottom part of acoustic ranges. The structural analysis and identification of dynamic parameters of such structures are extremely important in their monitoring to predict essential changes in dynamic characteristics. Moreover, the method of dynamic identification provides an opportunity to investigate the dynamic behavior of the given structure or source of signal *origin by researching investigated objects' to study informative characteristics. The article enters methodology for identifying the main structural parameters, such as main intrinsic frequencies, and the decrement in these frequencies. Particular interest represents seismo-acoustic monitoring of objects with sources of emission signals whose parameters are subject to definition and are characteristic of structure or signal origin. Emissions can carry both irregular and regular character. The latter case can be modeled as a flow with the likelihood characteristics and subject definitions. The result of the analysis of the data received in seismo-acustic monitoring of such signals is reduced to an estimation of parameters of an emission signal, which fluctuates from a signal to a signal. A practical method for analyzing natural and man-made objects, whose natural frequencies lie in the seismic and lower part of the acoustic frequency ranges, based on monitoring their dynamics, is proposed. A new approach is proposed for identifying the state of such objects. A non-traditional model of the natural background of the monitored object is proposed in the form of a superposition of Berlage impulses. Such a model makes it possible to estimate such an essential parameter in the description of an object as its quality factor, the dynamics of which can give an idea of its structural changes. To predict the behavior of natural and engineering objects to prevent undesirable consequences of the behavior of the object under study, seismo-acoustic monitoring systems are used. The mathematical model and algorithm proposed by the authors can be integrated into the system of seismo-acoustic monitoring of natural and man-made objects.*

Keywords: monitoring system, seismic signal, seismic wave, seismo-acoustic monitoring, mathematical model.

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