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USING BROADBAND SIGNALS FOR STRUCTURAL CHANGE DETECTION IN METAL DETAILS

Purpose. Realization of engineering structures in industrial and household spheres is based on materials that provide required strength, integrity and reliability during all period of exploitation. However, due to various reasons, most often excessive or cyclic load, metal changes its structure, which may lead to destruction of the structure. This situation creates need for improvement of existing components of system diagnostics and development of new ones. In particular, this refers to the part of formation and processing of signals in information-measuring channels which provide control in operating conditions. Thus, expansion of functional capabilities of information-measuring channels of diagnostics systems is relevant problem in the area of ensuring reliability requirements and exploitation safety.

Methodology. Analysis was performed using the method of spectral transformation of signal, integral locked loop of frequency and methods of approximation.

Findings. The result of this study is the non-dimensional coefficient of relation of bringing harmonics frequency (RBHF), absolute value of which indicates loss of energy in metal during oscillations and serves as an estimate of change in the structure of metal.

Originality. Proposed Methods for forming and digital processing of wideband signals based on the RBHF for diagnostic detection of changes in the metal structure which provide invariance to temperature fluctuations by using the signal frequency ratio. This allows increasing reliability and stability of information measuring channel of diagnostics system.

Practical value. While implementing the proposed method, we developed a procedure and hardware-and-software solutions for detecting structural changes in metal constructions based on changes of the RBHF coefficient.

Keywords: *wideband signals, diagnostic, structure changes, metal details, digital processing*

Introduction. Traditionally, the implementation of various engineering structures, both in the industrial and domestic spheres, is based on using metals. Such materials provide the appropriate durability, rigidity, reliability, and others throughout the life of the operation. However, due to various reasons, often excessive or cyclic loading, metal changes its structure, which can lead to destruction.

This situation leads to the need to improve the existing and to develop new diagnostic system components. In particular, this refers to the formation and signals processing in the information-measuring channels, which provide diagnosis in the operating conditions. Thus, the actual problem in the field of providing reliability and operational safety is the problem of expanding the functionality of measurement channels of diagnostic systems.

The object of study is processing of diagnosis signals based on the relative bringing harmonica frequency, which contain information about the state of the object.

The subject of study is methods and tools for digital processing of broadband diagnostic signals which will allow for an effective evaluation of the changes in metal elements of structures based on oscillations of the string sensor.

Purpose. To improve stability and functionality of the data-measuring channel of a system for diagnostics of engineering constructions.

Problem statement. The implementation of automated computer information and measurement systems for non-destructive testing is most often based on indirect methods for measuring mechanical parameters [1]. Practically, analysis methods of such mechanical parameters are widely used, because of their influence on oscillatory processes in the investigated details.

One of the most common sensor implementations used for the formation and processing of diagnostic signals are stretched strings. The strand forms the oscillatory system with the investigated detail. The components' mechanical properties of this system affect the oscillation of the string sensor. Thus, the initial data in the signals processing, based on the relative harmonics frequency (RBHF), is: the relative change in the higher mode frequency, depending on the elastic-plastic properties of the oscillatory system, the constituent part of which is a string sensor.

Literature review. Traditionally, the implementation of various engineering structures in the mining industry, such as metal frame mounting in mining, pipe structures and transportation systems of energy resources, etc., are based on the use of metals, providing adequate strength, rigidity, reliability, etc. operation. However, the metal changes its structure due to

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a variety of reasons, most often by excess or cyclic loading. These changes can lead to destruction.

Studies on stress concentrations in the surface layers by analytical exact [1] and approximate [2, 3] methods, as well as by experimental [4] method, limit equilibrium analysis of thin-walled structures with crack-like closing [5] and filled [6] defects, strength of the coated cracked shells [7] and material testing in order to determine their deformation [8, 9], strength and wear options [10, 11] give the opportunity to reliably predict the residual life of steel structures by their actual technical condition.

This situation stipulates necessity to improve the current and existing components of systems and develop new ones for diagnosing elements of metal structures of increased risk, in particular structures for mining. One of the current trends involves the methods and means of signal generation and processing in information-measuring channels, which provide diagnostics in operational conditions.

Implementations of automatic non-destructive computerized information-measuring systems are most often based on indirect methods for measuring mechanical parameters. Practically, methods of analysis of such mechanical parameters are widely used due to their influence on oscillatory processes in studied components.

One of the most common implementations of the sensor used to generate and process diagnostic signals is stretched strings [12]. The string forms an oscillatory system with the part which was studied. The mechanical properties of the components of this system affect the oscillations of the string sensor. The dynamics problems for one-dimensional structures immersed in medium with non-linear properties have been studied by analytical [13], numerical-analytical [14, 15] and numerical [16, 17] methods. The urgent task is to improve the existing and develop new methods of digital processing of diagnostic signals, which will allow providing an effective assessment of the change in the structure of metal structural elements by the vibrations of the string sensor. The input data for signal processing, at the relative harmonic frequency (RHF), are relative change in the frequency of higher modes, depending on the elastic-plastic properties of the oscillatory system, a component of which is a string sensor.

Processes that take place in metal parts during their operation are of interest, too. Structure changes cause changes in strain energy redistribution, the consequences of which can be observed by changing the relationship between mechanical stresses and deformations.

Method of formation of wideband diagnostic signals. A sensor string is an elastic element whose transverse vibration parameters depend on the force of tension, the elasticity of the string material and the mass of the oscillating sensor part. To excite oscillations in the system, the string is fixed between two points of the investigated part. That is, to the metal plate *2* between the pillars *3*, which are rigidly fixed on the surface of the plate, sensor string 1 is stretched. Transverse string fluctuations through the supports *3* are transferred to the base (Fig. 1, *a*).

The transverse wave propagation process in a string is described by the wave equation of the form [17]

$$\frac{\partial^2 y}{\partial t^2} = v^2 \cdot \frac{\partial^2 y}{\partial x^2},$$

where y is transverse coordinate; x is transverse coordinate; v is phase propagation velocity; t is time interval.

From the equation solution, we get a dependence which describes the eigen frequencies of transverse oscillations for an ideal elastic string, which has a fixed size, with a small amplitude of oscillations multiplied by its length

$$\omega_n = \sqrt{\frac{\sigma}{\rho}} \cdot k_n, \tag{1}$$

where σ is mechanical stress in a string; ρ is seamless string density; $k_n = 2\pi \cdot n/\lambda$ is the wave number; λ – the wavelength is equal to half the length L of the stretched string; n is the mod number.

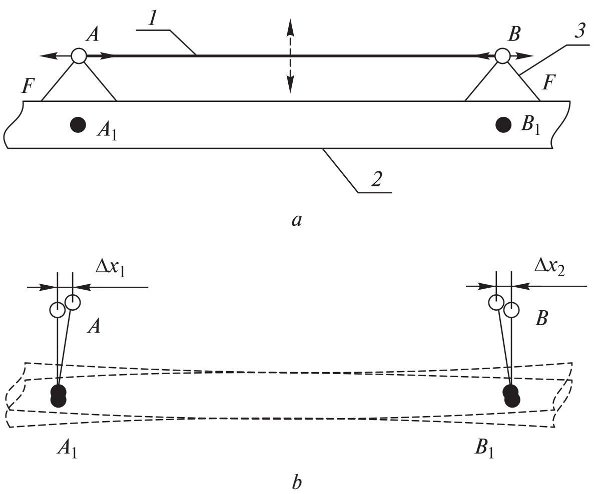


Fig. 1. The metal base deformation during the fluctuation of the strained string:

a – the scheme of the experimental installation; b – the kind of bending deformations that arise in the basis; 1 – sensor string; 2 – tested plate; 3 – pillar

The string oscillation, in general, is the sum of fluctuations of different modes. The oscillation frequency of real strings in higher modes does not correspond to (1). They can be calculated by the formula

$$\omega_n^2 \approx \frac{\sigma}{\rho} \cdot k_n^2 + \alpha \cdot k_n^4, \tag{2}$$

where α is positive constant due to its own stiffness of the string.

The string movement in a transverse direction is accompanied by a change in the force F in the longitudinal direction. During the oscillating cycle, the sensor string, deviating from its original position, deforms the base by bending it (Fig. 1, *b*).

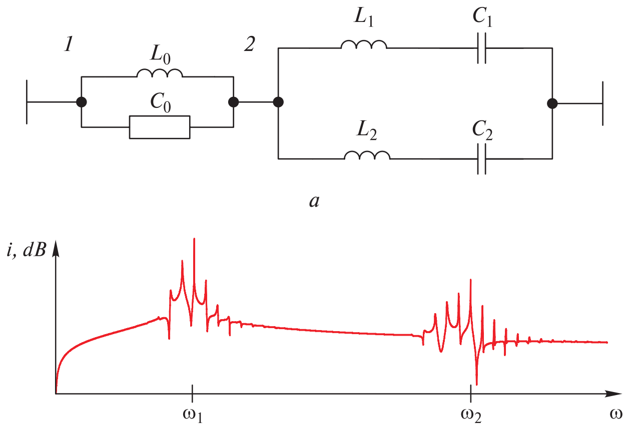
The string is returned to the initial position under the force action of counteracting the base. The relaxation processes in the base metal affect the resistive force speed. Therefore, the resultant oscillations of the string, stretched on the elastic-plastic basis, depend on its mechanical properties. The base oscillations cause frequency modulation of the string mod, and its plastic properties vary in a variety of modes with different numbers.

The oscillating system, which consists of strings stretched on an elastic-plastic base, is modeled on the basis of the substitution scheme (Fig. 2, *a*). The scheme is based on the electromechanical analogies principles. In addition, for the model simplification, only two modes are considered. The properties of two string modes are modeled by the parallel-connected links L_1, C_1 and L_2, C_2. The elastic-plastic base properties are simulated in parallel-connected L_0, G_0.

On the basis of the proposed model, the spectral properties of the current flowing to the common line are investigated. The electric model current is equivalent to the force applied to the base. Spectral current density found as a result of a numerical experiment is shown in Fig. 2, *b*. From the above simulation results, we can see that the oscillation spectrum for each mode is symmetric relative to ω_1 and ω_2.

This is typical of frequency-modulated signals. The bandwidth occupied by the mode depends on L_o – that is, on the base elastic properties. The L_o decrease, which is equivalent to the increase in the base stiffness, leads to a narrowing of the band around the central spectral components at frequencies ω_1 and ω_2. The conductivity G_o decrease, which is equivalent to reducing the plasticity of the material, leads to changes in ω_1 and ω_2.

It is well-known [18] that relaxing processes that are sensitive to the metal structure appear differently in different ways



a

b

Fig. 2. Electromechanical model of the oscillatory system:

a – Electromechanical model scheme of oscillatory system; b – signal spectral density is proportional to the oscillation amplitude of the tensioned strand stretched on a plastic-elastic basis

at different frequencies. The frequencies of all modes, in proportion to their number, depend on the physical dimensions of the oscillatory system elements. Accordingly, an integral part of such a system is the string sensors and the investigated detail. With slight fluctuations in temperature, it affects only the change in geometric sizes and also changes all mode frequencies proportionally. Thus, it is advisable to consider the oscillation frequency of the first mode taken as a reference. The deviation of the higher mode frequencies from the frequency multiplicity of the first mode indicates various deformation energy losses in the oscillatory system in the case of applying an effort with different frequency. The deviation degree can be estimated using a coefficient that determines the relative bringing harmonics frequency (RBHF) by the formula

$$q_n = \frac{n \cdot \omega_{base}}{\omega_n}, \tag{3}$$

where n is the mode number; ω_{base} is the 1^{st} mode oscillation frequency; ω_n is the n^{th} mode oscillation frequency.

For an ideal tensioned string whose ends are fixed, this ratio will be equal to 1. In real sensor strings, whose stiffness is determined not only by the tension force but also by the own stiffness of the material taken into account in (2), q_n will be less than 1. Changes in the metal structure, which lead to the deformation energy redistribution of the elastic-plastic base, have a different effect on the sensor string tension. In the presence of significant losses of deformation energy associated with the metal plastic properties on which the string is tensioned, the coefficient q_n will be greater than 1.

To find the RBHF, which is estimated by the coefficient q_n, a pilot installation was developed and manufactured. The installation functional scheme includes a mechanical unit, an electronic unit for maintaining oscillations, as well as a unit for determining the frequency modulation ratios of the first mode harmonics, Fig. 3.

The sensor string *1* is stretched between the supports *3*, which are firmly fixed on the investigated basis *4*. The string part is in a magnetic field, which creates a permanent magnet *2*.

As a result, the sensor oscillation in one plane, which is supported by oscillation support unit (OSU), is formed. In the case of transverse vibrations of a string, consisting of a vibrational system formed by the string, supports and the base, a signal $s(t)$ is formed.

Next, the signal enters the error detection unit (EDU), which generates a control signal of a voltage controlled oscillator (VCO). The VCO is tuned to m harmonics of the first mode. The signal $fnd(t)$ is obtained by dividing the VCO frequency by m, equal to the sensor's first mode frequency, which is taken as the reference. The microprocessor unit (MU) selects the harmonic for research and displays the corresponding signals at the unit input VCO and band-pass filter (BPF). In this case (BPF), the signal from the input signal emits a mode $sn(t)$, and the generator generates a harmonic signal of the reference frequency $fn(t)$ with the corresponding number. The reversing counter (RC) calculates the difference in the pulses number of these two signals, and the MU seeks the frequencies ratio by the difference of *CNT*.

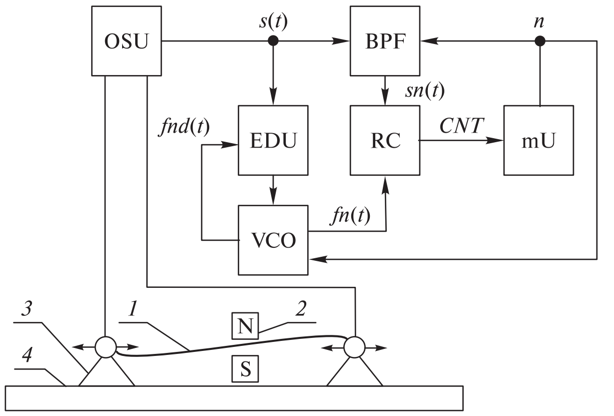


Fig. 3. Structural scheme of the installation to determine the RBHF estimation:

1 – sensor string; 2 – magnet; 3 – pillar; 4 – tested plate

The string sensor excitation provides a source of broadband signal, which actually forms its initial displacement. The sensor electrical impedance depends on its own frequencies. Using a string sensor in the feedback loop of the amplifier, a self-oscillating system was obtained. That is, the signal is formed by moving the sensor in a magnetic field at natural frequencies of the oscillatory system. The functional scheme of the unit for maintaining the oscillation is shown in Fig. 4.

The broadband exciting signal source *6* provides a current in sensor *1*, which leads to its displacement [19]. The sensor oscillation in a magnetic field leads to the appearance of an EMF at its ends. The received EMF is amplified by the unit *3* and after the transformation into current, current source *2*, it returns to the sensor string, supporting its oscillations at natural frequencies of the oscillatory system.

The amplitude of the amplified EMF at the unit *3* output is evaluated by the auto-amplification system *4*, and at reaching the given level, the gain of block *3* decreases. Due to the auto-amplification system, the string oscillation amplitude remains stable. Thus, in the signal there are only frequency components associated with the modes of the sensor as part of the oscillatory system.

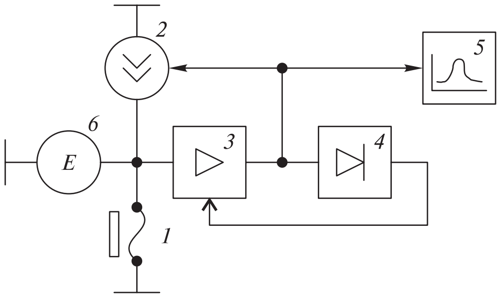


Fig. 4. Structural scheme of the oscillation maintenance block:

1 – sensor string in a magnetic field; 2 – current source; 3 – voltage amplifier with controllable gain; 4 – automatic amplifier rectifier; 5 – RBHF assessment unit; 6 – broadband excitement signal source

Method for processing diagnostic signals to detect structural changes in metal constructions. To estimate the first mode frequency, which is modulated by bending fluctuations of the base by frequency, it is proposed to use the VCO. The first mode signal occupies a certain frequency band, so initially the VCO is tuned to the first mode central frequency. After setting the VCO, a deviation of its frequency is found multiplied by the studied mode number from the mode frequency for this number. The basis of the auto-tuning VCO frequency subsystem is the forming of an error signal unit. The signal from the oscillation support unit output enters the band-pass filter, which allocates the frequency band with the first mode . This signal is used to adjust the VCO frequency to the middle of the first mode band.

The error signal used for control (CVG) is determined by the heterodyne transfer of spectrum at the frequency axis beginning.

For this purpose, sampling is used by two auxiliary impulse signals generated using the VCO. As a result, the input signal spectrum becomes periodic with the discrete pulse sequence period. The frequency of one pulse signals must be known to be lower than the central frequency of , and the frequency of another is higher. Thus, the spectrum of sampled signals and will shift to zero frequency, Fig. 5. In addition, spectrum will be mirrored, but with symmetry of the input signal spectrum this does not matter.

The spectral components S_{D1} and S_{D2} are at a distance of $\Delta\omega_1$ and $\Delta\omega_2$ from zero. For the condition $\Delta\omega_1 = \Delta\omega_2$, the frequency ω_{base} will be between S_{D1} and S_{D2}. Setting VCO error to frequency ω_{base} is $\Delta\omega = \Delta\omega_1 - \Delta\omega_2$. To search $\Delta si(t)$, which is proportional to $\Delta\omega$, a low frequency filter with a amplitude-frequency characteristic of the near-incident line is used. A unit that generates signal amplitude that is inversely proportional to the frequency increase is a low frequency filter. By subtracting the signals amplitude that have passed this filter, we obtain the error signal of symmetry ω_{D1} and ω_{D2} relative to ω_{base}. The structural scheme of the frequency auto-adjusting subsystem VCO to the basic harmonic of the sensor first mode signal is shown in Fig. 6.

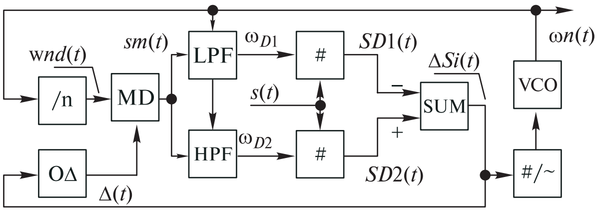


Fig. 6. The structural scheme of the auto-adjustment subsystem VCO to the diagnostic signal central frequency

For the sampling signals ω_{D1} and ω_{D2} with a frequency higher and lower than the frequency *fnd*(*t*) VCO, which are precisely shifted to a fixed value, a modulator (MD) with amplitude balanced modulation was used. The modulated signal is *fnd*(*t*) and the modulating signal is $O\Delta(t)$. The signal $O\Delta(t)$ is generated by the frequency delta generator $O\Delta$. The modulated signal *sm*(*t*) contains only two frequency components, which are symmetric relative to the carrier frequency. Formation of the lower and upper frequency signals of sampling ω_{D1} and ω_{D2} is completed by digital filters, respectively, LF and HF. The cutoff frequencies of digital filters are set to *fn*(*t*). The input signal with the selected lane of the first mode $s_1(t)$ enters the sampler (#) and then evaluates the spectrum difference Δ.

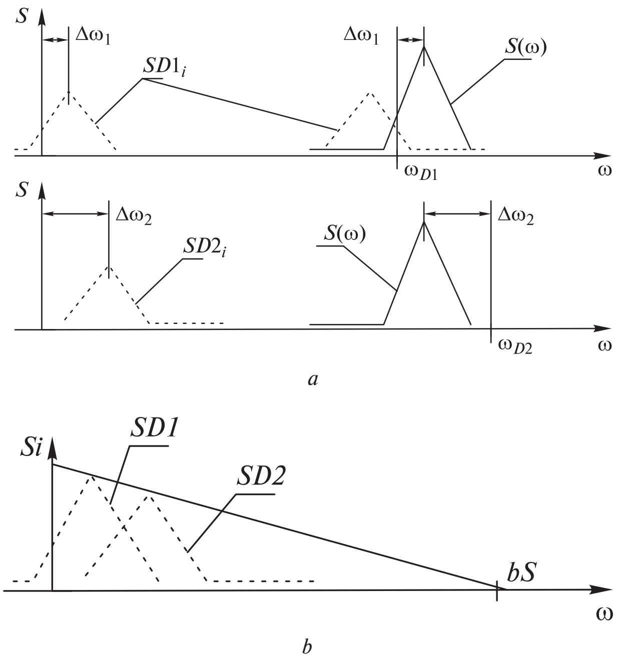


Fig. 5. Method for receiving a VCO configuration signal:

a – change in input signal spectral density after sampling with different frequency; b – amplitude-frequency characteristic of the integral estimation unit; bS – signal processing band limit

Frequency control VCO is carried out by a signal proportional to the discrepancy between discrete oscillation frequencies $\Delta si(t)$. Depending on the sign $\Delta si(t)$, the frequency *fn*(*t*) will increase or decrease. When reaching the value at which *fn*(*t*) after dividing by *n* coincides with the central input signal $\Delta si(t)$ frequency approaches 0. The signal at the output of the control unit (#/~) controls VCO so that it approaches 0. As a result of the integrated estimation of the spectra of the sampled signals, the integral equality of their spectral components is maintained, Fig. 7.

In order to increase the accuracy of the processing of the input signal, the frequency of the generator $O\Delta$ decreases. This leads to a decrease in the difference between the signal frequencies $\omega_{\Delta 1}$ and ω_{D2}, also reduces the requirements for the symmetry of the input signal spectral density and improves the accuracy of setting VCO to the reference frequency.

If the generator $O\Delta$ frequency will depend on the voltage, then the width of the processing band can be changed during the setup. The initial setting is *fnd*(*t*) VCO at the spectral density middle. After the VCO frequency setting, the error signal decreases to 0.

This delay signal module is used to control the frequency-$O\Delta$. With a significant deviation VCO of ω_{base}, frequency $O\Delta$ is

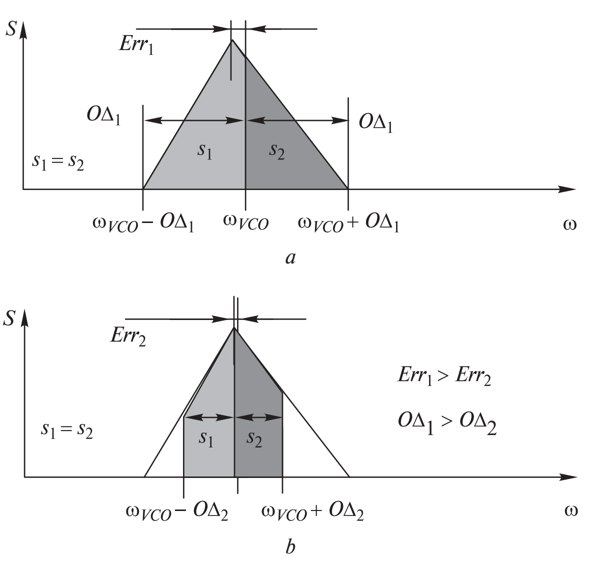


Fig. 7. Effect of bandwidth processing on accuracy of setting VCO with asymmetric spectral density of the input signal:

a – wide gate; b – narrow gate

also high. By reducing the deviation with delay, the frequency will decrease by $O\Delta$. This will reduce the frequency band of the input signal processing and increase the accuracy of VCO setting. The structural scheme of frequency $O\Delta$ control subsystem is shown in Fig. 8.

With the described circuits the device is tuned to the frequency within the selected band. The result of subsystems operation is a signal $fnd(t)$ with a frequency by n times higher than the first mode frequency ω_{base}. Using $fnd(t)$ after dividing it by turns by $n/2$, $n/3$, etc. we get a signal $fn(t)$ with frequencies equal to 2, 3, etc. first sensor mode harmonics. The input signal $s(t)$, which contains the spectral components of the sensor (strings) oscillation frequencies, enters an additional (BF) that alternates the frequency band in the frequency fluctuations vicinity of the n^{th} mode $sn(t)$, Fig. 9.

The reference frequency signal from the VCO enters the input subtraction of the reversing counter, and the signal from the filter output – to the addition input of a reversing counter. At the reversing counter output, the difference signal between the mode frequency and the reference frequency CNT = $sn - fn$ is formed.

The frequency difference is used as the output information about the mode frequency deviation and the reference signal harmonic. At a small difference between the signal frequencies, the output signal during the measurement of the frequency varies discretely, Fig. 10.

The frequency difference can be measured with a direct reference. That is, for a certain time, one is to count impulses $fn(t)$ and $sn(t)$, and then look for their share by the formula (3). To increase the measurements accuracy, with a small difference in signal frequencies, it is necessary to increase the frequency measurement time.

The difference signal is a linear function that allows it to be described by the dependence of the form

$$CNT(t) = K_0 + K_1 \cdot t. \tag{4}$$

Coefficients K_0 and K_1 are determined on the basis of regression analysis using observation of a reversing counter output, which corresponds to the difference in the diagnostic signal frequency. The input sequence for monitoring the reversing counter output $y_i = CNT(t)$ is determined through fixed time intervals. This sequence, based on (4), can be presented in the matrix form

$$Y = XK - E, \tag{5}$$

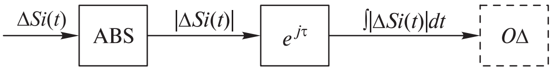


Fig. 8. The structural scheme of the subsystem of input signal processing frequency band control

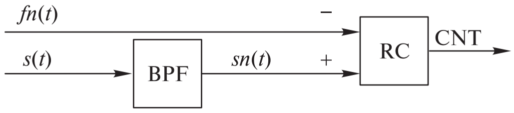


Fig. 9. The structural scheme of the unit for determining the frequency difference of the diagnostic signal

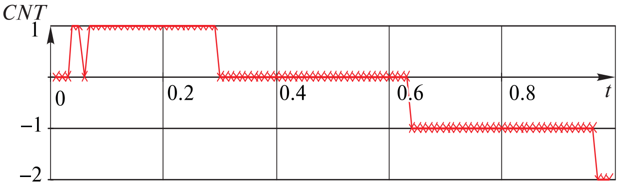


Fig. 10. The frequency difference signal form at the reversing counter output

where K is the vector-column of parameters of the linear regression equation with dimension 2; E is the vector column of deviations of collected values with dimension N; Y is the value column $y_i = CNT(i \cdot \Delta\tau)$.

Expressing from (5) the vector of deviations

$$E = Y - XK,$$

according to the method of least squares, we require its minimality by the formula

$$\sum_{i=1}^{N} e_i^2 = E^T \cdot E = \left(Y - X \cdot K\right)^T \cdot \left(Y - XB\right) \to \min. \tag{6}$$

Condition (6) is satisfied if the vector-column of coefficients K is found by the formula

$$K = (X^T X)^{-1} X^T Y.$$

By the linear regression coefficients we find the coefficient (3) as follows

$$sn_i - fn_i = K_0 + K_1 \cdot i \quad \frac{fn_i}{q} - fn_i = K_0 + K_1 \cdot i;$$

$$q = \frac{fn_i}{\left(K_0 + K_1 \cdot i\right) + fn_i}.$$

Adopting a factor matrix

$$X = \begin{pmatrix} 1 & 1 \\ 1 & 2 \\ 1 & 3 \\ 1 & .. \\ 1 & N \end{pmatrix}, \tag{7}$$

find the coefficient vector K of the regression model for N values found within the interval T.

The RBHF q coefficient sought by the formula

$$q = \frac{fn}{\dfrac{K_0 + N \cdot K_1}{T} + fn}.$$

Thus, the expression (7) allows us to describe the RBHF coefficient based on the regression model.

Experiments. In the signals study, the effectiveness of using a regression model with the help of a numerical experiment was evaluated, as well as testing on existing metal constructions models. Coefficient q was searched in two ways: by measuring the reference oscillation harmonic ratio and the higher oscillation frequency, using the reference method of frequency measurement; using the searching method for regression model searching. For search, 150 observations were used, which were uniformly determined over the studied interval. Research results of both ways for two time intervals are given in Table.

From the research results we can see that, within small observation time, the results obtained with the help of a regression model are more accurate with respect to the frequency ratio. This is especially important for frequencies at small deviations for which q is in area 1.

On the basis of the proposed method an information-measuring channel was developed based on the primary converter with a string sensor. Similar experimental studies were also conducted. During the development and processing of diagnostic signals, test models from different mothers were used. In particular, the pipe steel 09G2FB, structural steel C3, made according to the recommendations. The supports are made of a 40 × 40 × 5 beam, between which the sensor element was fixed – a stretched metal string. The sensor oscillation, after the excitement of a broadband signal, was supported by an oscillator.

Table

The measurement results of the diagnostic signal frequency ratio

q specified value	determined by 1 s method		determined by 0.5 s method	
	frequency ratio	regression model	frequency ratio	regression model
1	1	1.000036	1	0.999973
1.0001	1.00049	1.000147	1	1.000059
1.001	1.00099	1.001041	1.000998	1.001003
1.01	1.009985	1.010073	1.00998	1.010021
1.1	1.100349	1.100049	1.0998	1.099967
1.5	1.50025	1.500046	1.5	1.499842
2	2	1.99997	1.99902	1.999941

Results. Using the coefficient value of the frequency ratio obtained, it is easy to estimate the relative reduced error of definition for the time 1s and 0.5s, Figs. 11 and 12, respectively.

As can be seen from the graphs, using a regression model, it is possible to improve the ratio accuracy of the two frequencies ratio, especially if there are small frequency deviations.

In addition, as a result of experimental studies, the first mode harmonics frequency ratio is obtained to the higher mode frequency for the various models from the standard steel tube 09G2FB of the standard type for the tensile fracture study. The results of these studies are shown in Fig. 13.

Discussion. Changes in the mechanical properties of metal components, during operation, affect the structure reliability as a whole. As a result, many scientific studies are devoted to the consideration of physical processes that occur during metal model deformations. In carrying out the above-mentioned studies, non-destructive methods are used to detect changes in the metal structure. In particular, these are the coercive forces study, the propagation velocity of acoustic oscillations, changes in the polarization potential of the part surface. In addition, various destructive methods are widely used.

The proposed approach of indirect evaluation of the base elastic-plastic properties, by excited oscillations in the metal base with the help of supports between which the metal string is tensed, extends the functional capabilities of non-destructive methods. The string sensor can be integrated into a metal structure. In particular, it is fixed on the structural elements of bridges, supports, cranes, and others, and operates the entire lifetime. Such an approach will allow for constant monitoring of construction status.

The proposed automatic frequency adjustment method, based on the variable width of the holding bandwidth the diagnostic signal, allows one to increase the accuracy of setting the frequency to the middle of the spectral density of the first string mode. Investigation of the relative reduced frequency of the mechanical system oscillation harmonic showed that they can be applied to multimode oscillations.

Conclusions. The scientific novelty of the research is that for the first time it is proposed to use the coefficient of estimation of the relative bringing harmonics frequency of string sensor oscillation to detect structural changes in the metal details of mechanical structures under operating conditions.

The practical significance of the obtained results is that the appropriate structural, circuit and algorithmic solutions for the implementation of a digital system for the formation and processing of diagnostic signals are developed, based on the proposed method. The main advantages of the digital system are the functional components for generator frequency adjustment of the reference generator with the processing band width control. Given the high stability of the string sensor parameters and its low cost, the proposed mechanism of oscillation excitation extends the proposed method functionality.

Research results on the relative bringing harmonics frequency of the oscillations can be used in systems with a fixed size and distributed masses of oscillating elements, in particular beams, plates, acoustic chambers, and others. Thus, further research can be used as basis for development of computer diagnostic systems that rely on autonomous distributed sensory modules. The work is supported by the state budget

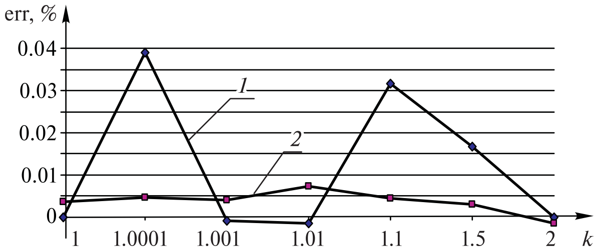


Fig. 11. The relative error in determining the frequency ratio given at 1 s measure:

1 – f_1/f_2; 2 – proposed method

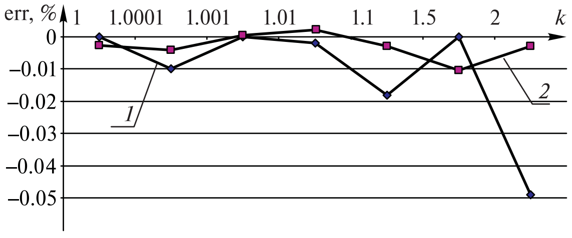


Fig. 12. The relative error in the frequency ratio determination given at 0.5 s measure:

1 – f_1/f_2; 2 – proposed method

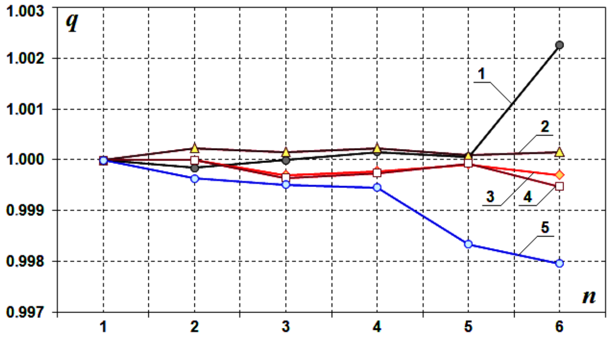


Fig. 13. The values of coefficients q for different numbers of modes:

1, 2 – models with plastic-deformed area; 3 – sample with weld seam; 4 – sample with transverse cutouts; 5 – sample test

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Використання широкосмугових сигналів для виявлення структурних змін металевих деталей

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Мета. Реалізація інженерних конструкції у промисловій і побутовій сферах ґрунтується на використанні металів, що забезпечує відповідну міцність, жорсткість та надійність протягом терміну експлуатації. Однак, унаслідок різноманітних причин, найчастіше надлишкового чи циклічного навантаження, метал змінює свою структуру, що може призвести до руйнування конструкції. Така ситуація призводить до необхідності вдосконалення наявних і розробки нових компонентів систем діагностування. Зокрема, у частині формування та опрацювання сигналів у інформаційно-вимірювальних каналах, що забезпечують контроль в експлуатаційних умовах. Таким чином, метою досліджень є вирішення проблеми в області забезпечення вимог надійності та експлуатаційної безпеки, зокрема, розширення функціональних можливостей інформаційно-вимірювальних каналів систем діагностування.

Методика. Опрацювання реалізовано на основі методу спектрального перетворення сигналу, інтегрального автоналаштування частоти, а також методів апроксимації.

Результати. Результатом дослідження є безрозмірний коефіцієнт відношення приведеної частоти гармоніки (ВПЧГ), абсолютне значення якого вказує на наявність втрат енергії в металі при його деформації внаслідок коливання та опосередковано служить оцінкою зміни структури металу.

Наукова новизна. Запропоновані методи формування й цифрового опрацювання широкосмугових діагностичних сигналів за ВПЧГ для виявлення змін структури металу, який забезпечує інваріантність до флуктуації температури за рахунок використання відношення частот, що дозволяє підвищити стабільність інформаційно-вимірювального каналу системи діагностування.

Практична значимість. У ході реалізації запропонованого методу був розроблений спосіб і апаратно-програмні рішення для виявлення структурних змін у металевій конструкції із зміною коефіцієнта діагностичних сигналів на основі відносної приведеної частоти гармонік.

Ключові слова: *широкосмугові сигнали, діагностування, структурні зміни, металеві деталі, цифрове опрацювання*

Использование широкополосных сигналов для обнаружения структурных изменений металлических деталей

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Цель. Реализация инженерных конструкций в промышленной и бытовой сферах основывается на использовании металлов, обеспечивает соответствующую прочность, жесткость, и надежность в течение срока эксплуатации. Однако, вследствие различных причин, чаще всего избыточной или циклической нагрузки, металл меняет свою структуру, что может привести к разрушению конструкции. Такая ситуация приводит к необходимости совершенствования имеющихся и разработки новых компонентов систем диагностирования. В частности, в части формирования и обработки сигналов в информационно-измерительных каналах, обеспечивающих контроль в эксплуатационных условиях. Таким образом, целью исследований есть решение проблем в области обеспечения требований надежности и эксплуатационной безопасности, в частности, расширения функциональных возможностей информационно-измерительных каналов систем диагностирования.

Методика. Обработка реализована на основе метода спектрального преобразования сигнала, интегральной автоподстройки частоты, а также методов аппроксимации.

Результаты. Результатом исследования является безразмерный коэффициент отношения частоты гармоники (ОПЧГ), абсолютное значение которого указывает на наличие потерь энергии в металле при его деформации вследствие колебания и косвенно служит оценкой изменения структуры металла.

Научная новизна. Предложены методы формирования и цифровой обработки широкополосных диагностических сигналов на основе ОПЧГ для обнаружения изменений структуры металлических деталей, которые обеспечивают инвариантность к флуктуации температуры вследствие использования соотношения частот, что позволяет повысить надежность работы и стабильность информационно-измерительного канала диагностической системы.

Практическая значимость. В процессе реализации предложенного метода был разработан способ и аппаратно-программные решения для выявления структурных изменений в металлической конструкции с изменением коэффициента диагностических сигналов на основе относительной приведенной частоты гармоник.

Ключевые слова: *широкополосные сигналы, диагностирование, структурные изменения, металлические детали, цифровая обработка*

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